Designing Sustainable Landscapes: Terrestrial barriers settings variable

A project of the University of Massachusetts Landscape Ecology Lab

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Reference:

McGarigal K, Compton BW, Plunkett EB, DeLuca WV, and Grand J. 2018. Designing sustainable landscapes: terrestrial barriers settings variable. Report to the North Atlantic Conservation Cooperative, US Fish and Wildlife Service, Northeast Region.

General description

Terrestrial barriers is one of several ecological settings variables that collectively characterize the biophysical setting of each 30 m cell at a given point in time (McGarigal et al 2017). Terrestrial barriers measures the relative degree to which roads and railroads may physically impede movement of terrestrial organisms. It is derived by assigning an expert-derived score to each road/railroad class to reflect the increasing physical impediment of larger roads, and adjusting these scores at road-stream crossings (i.e., bridge or culvert) based either on a custom algorithm applied to field measurements of the crossing structure or predictions from a statistical model (see below for details) to reflect increased passability of terrestrial organisms through the crossing structure. Terrestrial barriers is scaled 0-5, where roads and railroads are assigned values >0 (indicating the relative degree of impediment) and all other cells are assigned 0 (**Fig. 1**).

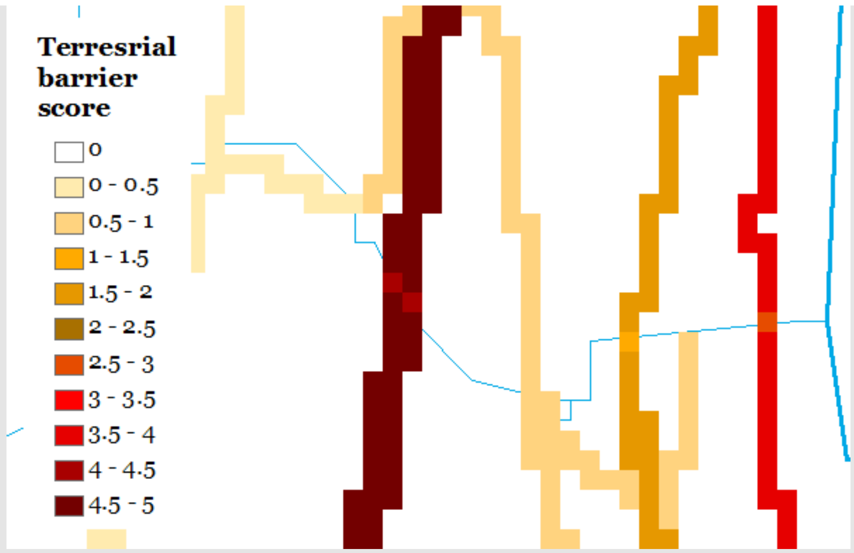

Figure 1. Terrestrial barrier scores for roads and railroads, with streams in blue. Note the reduced score at road-stream crossings.

Use and interpretation of this layer

Terrestrial barriers is used in the derivation of the connectedness metric in the context of the broader assessment of ecological integrity (see the technical document on integrity, McGarigal et al 2017). It is a measure of the degree to which a road or railroad is predicted to be an impediment to movement of terrestrial organisms, and its use should be guided by the following considerations:

- Terrestrial barriers is formatted as a raster GIS data layer designed for use in the DSL Landscape Change, Assessment and Design (LCAD) model. It contains non-zero values only for cells classified as either road or railroad in Open Street Maps (OSM); all other cells are assigned a value of 0. As such, it is a difficult layer to view at small map scales since the eye is naturally drawn to the dominant matrix of zeros. For easier viewing and general purpose use, it is probably best to view this layer at 1:100,000 scale or larger.
- It is important to recognize the relative nature of the terrestrial barrier scores. A score of 0 indicates the absence of a road/railroad structure; a score of 5 for a motorway

indicates that it confers roughly 5 times the physical impediment to movement than, say, a local road with a score of 1. Thus, non-zero values indicate the relative degree of obstruction to the movement of terrestrial organisms. Because the score is a relative index, the values do not have a simple absolute interpretation. Moreover, because the score is an index to passability for all terrestrial organisms, but emphasizing vertebrates, it does not have an exact interpretation for any single species. Nevertheless, it may be useful to think of the index as roughly translating into the relative likelihood of a terrestrial organism choosing to avoid crossing the road/railroad due to the intimidating physical structure of the road/railroad. Note, the likelihood of being killed while crossing the road is more directly addressed with the road traffic setting variable.

- It is important to acknowledge that the terrestrial barrier scores are derived from a model, and thus subject to the limitations of any model due to incomplete and imperfect data, and a limited understanding of the phenomenon being represented. In particular, the GIS data on roads/railroads and road-stream crossings are imperfect; they contain errors of both omission (e.g., missing roads and/or road-stream crossings) and commission (e.g., roads and/or derived road-stream crossings that don't exist in the real world). In addition, the GIS data do not contain consistent and reliable information on local factors affecting passability, such as the presence of roadside fencing and median barriers. Consequently, there will be many places where the model gets it wrong, not necessarily because the model itself is wrong, but rather the input data are insufficient or wrong. In addition, the scores themselves are derived from expert opinion, and these scores are modified at road-stream crossings based on an expert model based on expert opinion of the factors affecting passability for terrestrial organisms. While the model incorporates many of the factors known or believed to affect terrestrial passability, it is almost certainly an incomplete and imperfect representation of the real-world factors affecting passability. Moreover, the vast majority of road-stream crossings have not been surveyed in the field, and their predicted terrestrial barrier scores are based on an even simpler and less perfect model derived from GIS data. Thus, terrestrial barriers should be used and interpreted with caution and an appreciation for the limits of the available data and models.
- While terrestrial barriers has a wide variety of potential uses, perhaps its most significant application is to aid in the assessment of terrestrial connectivity via incorporation into the DSL connectedness metric and assessment of ecological integrity and critical linkages (i.e., prioritization of road passage structures).

Derivation of this layer

Data sources

- Open Street Map (OSM). We used this open-source global map of roads (http://www.openstreetmap.org) as our source of linework for roads and railroads. Data were downloaded in July 2015.

- Road-stream crossings, derived from vector roads, railroads, and National Hydrography Dataset (NHD) stream centerlines.
- Modeled and field-surveyed passability scores for culverts and bridges, based on data from the North Atlantic Aquatic Connectivity Collaborative (NAACC).

Algorithm

Terrestrial barrier scores were assigned separately for roads/railroads, surveyed road-stream crossings and unsurveyed road-stream crossings, as follows:

1. Terrestrial barrier scores for roads/railroads

Terrestrial barrier scores for roads/railroads were subjectively assigned by road class to reflect the relative physical impediment they confer to terrestrial animal movement (**Table 1**). Note, abandoned railroads were not treated as a barrier, in part because we assumed that the rails have been removed.

Table 1. Assignment of terrestrial barrier scores to classified roads/railroads.

Road class	Terrestrial barrier score
motorway	5
primary highway	2
secondary highway	1
tertiary highway	1
local road	1
track	0.5
railroads	4

2. Terrestrial barrier scores for road-stream crossings

We derived road-stream crossings in the landscape based on the intersection of the cleaned and trimmed vector National Hydrography Dataset (NHD) streams and Open Street Map (OSM) roads and railroads. Each of these point crossings was then moved to the nearest crossing pixel in the raster representation of the streams and roads for representation in the terrestrial barriers layer. However, we retained both the original (vector) and moved (cell) locations for subsequent use (see below). We assigned a terrestrial barrier score to each crossing in the raster representation, but the derivation of the score depended on whether the crossing was surveyed in the field or not, as described below. Each crossing received a terrestrial passability score, from 0 (impassable) to 1 (a big span with a lot of upland crossing), which was transformed into a terrestrial barrier score as follows:

$$\text{tbarriers}' = \text{tbarriers} \times (1 - (\text{passability} \times 0.9))$$

Thus, at each road-stream crossing the terrestrial barrier score based on road class (**Table 1**) is multiplied by the complement of the terrestrial passability score x 0.9. Consequently, a perfect passability means a 90% reduction in the terrestrial barrier score. For example, a road-stream crossing on a motorway (score = 5) having maximum passability (1) would result in a final terrestrial barrier score of 0.5, indicating that there would be only a minor impediment to movement of terrestrial species at the point of the crossing structure.

2.1. Surveyed road-stream crossings

To assign terrestrial barrier scores for surveyed road-stream crossings we used an assessment protocol and scoring system developed by the North Atlantic Aquatic Connectivity Collaborative (NAACC) and its predecessor, the Stream Continuity Project. The protocols were developed for implementation by trained volunteers or technicians and rely on information that can be readily collected in the field without surveying equipment or extensive site work. The Collaborative also created an algorithm for scoring crossing structures according to the degree of obstruction they pose to terrestrial organisms (i.e., passability) based on field-measured variables. The scoring algorithm is currently being revised by the Collaborative. The current terrestrial barriers layer is based on the algorithm developed in 2010. We used scores based on the 2010 scoring algorithm for a set of 6,774 crossings after considerable filtering of the original crossings database (see **Appendix**) to ensure correspondence with our derived road-stream crossings.

The 2010 scoring algorithm was based on the opinions of experts who decided both the way to score each predictor and the way to combine them into a single index. Scoring involved two steps: 1) generating a component terrestrial passability score for each predictor variable, and 2) combining these predictions to generate a final terrestrial passability score for the crossing (which was subsequently transformed into a terrestrial barrier score as described above).

1. *Scoring individual predictors*

   Terrestrial passability was based on the following five variables in the crossings database:

   V1 = Openness (of the largest structure for a crossing)

   V2 = Substrate

   V3 = Span

   V4 = Height (minimum height of the largest structure at the crossing)

   V5 = Width (minimum width of the largest structure at the crossing)

   V1 = Openness was computed for the largest structure at a crossing as the cross-sectional area of the inlet or outlet (ft^2), whichever was smaller, divided by crossing length (ft). Openness was considered by far the most important variable and was given a weight of 0.9. Openness scores were continuous based roughly on the values in **table 2** as depicted in **figure 2**.

Table 2. Assignment of terrestrial barrier scores to classified roads/railroads.

Openness (ft)	Terrestrial passability score
0	0
0.825	0.2
1.24	0.4
1.65	0.6
2.475	0.78
3.3	0.85
6.6	0.95
10	1.0

V2 = Substrate types were assigned terrestrial passability scores as given in **table 3**. Substrate type was considered to be of minor but not negligible importance, and thus was given a weight of 0.1.

Table 3. Assignment of terrestrial barrier scores to substrate types.

Substrate type	Terrestrial passability score
Inappropriate	0
None	0.5
Contrasting	0.75
Comparable	1.0

V3 = Span types were assigned multiplier values, as given in **table 4**, which were used to compute the overall terrestrial passability score (see below). Span was deemed to be of primary importance when the channel is severely constricted. Presumably under these conditions there is rarely, if ever, dry passage through the structure and water velocities for much of the year are likely to be high. Thus, span was treated as a multiplier on the weighted average score from V1 and V2.

Table 4. Assignment of terrestrial barrier scores to span types.

Span type	Multiplier
Severe constriction	0.6
Mild constriction	0.8
Bankfull	0.95
Channel & Banks	1.0

V4 = Height was defined as the minimum height (ft) of the largest structure at a crossing. Height scores were continuous based roughly on the values in **table 5** as depicted in **figure 2**.

Table 5. Assignment of terrestrial barrier scores to structure height.

Height (ft)	Terrestrial passability score
0	0
1	0.1
2	0.2
3	0.3
4	0.4
5	0.5
6	0.6
7	0.7
8	0.8
9	0.9
10	1

V5 = Width (ft) was defined as the minimum width of the largest structure at a crossing. Width scores were continuous based roughly on the values in **table 5** as depicted in **figure 2**.

2. *Combining component scores into the overall barrier score*

The individual component scores from step 1 above were combined using the following formula to generate the overall passability score for the observed crossing:

Passability score = (0.9V1 + 0.1V2) × V3, limited by V4 and V5

Thus, the baseline score was derived from a weighted combination of V1 (openness) and V2 (substrate), with the bulk of the weight on openness. V3 (span) was treated as a multiplier on V1 and V2. Consequently, the final passability score was discounted for structures that do not span both the channel and banks. For structures with severe constrictions the maximum attainable passability score was 0.6. V4 and V5 (structure height and width, respectively) are already accounted for to some degree in V1 (openness). However, there are some absolute limits to how small a structure can be and still effectively pass wildlife. For example, a small culvert beneath a railroad track or bike path might have a favorable openness score, but still be too small for many wildlife species. Therefore, V4 (height) and V5 (width) were set up as limiting variables, so that regardless of the score generated using V1 (openness), V2 (substrate) and V3 (span), the final score can be no higher than the scores associated with height and width.

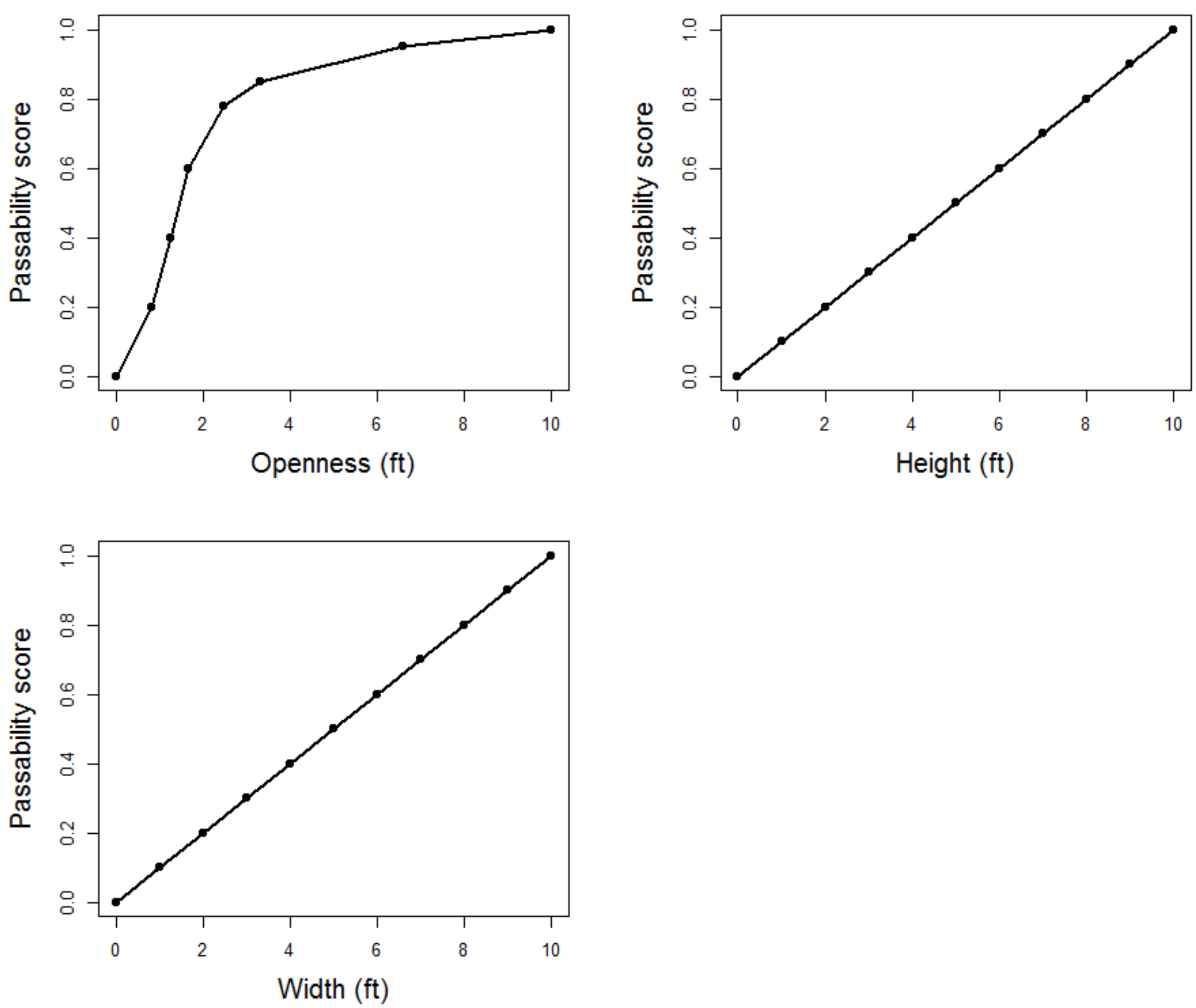

Figure 2. Functions for transforming the continuous predictor variables (openness, height, and width) into terrestrial passability scores scaled 0-1 for inclusion in the calculation of terrestrial barrier scores.

2.2 Unsurveyed road-stream crossings

To assign terrestrial barrier scores for those crossings that had not been assessed in the field (i.e., unsurveyed crossings), we used GIS data and crossing scores from the filtered set of 6,774 crossings (see **Appendix**) to create a statistical model to predict terrestrial barrier scores, as follows.

1. We assembled a suite of predictors to be used in the model either by sampling grids at the cell location of the crossing or by analysis of a window centered on the crossing (**Table 4**). For the scale-dependent variables, we calculated their values in square windows with sides of 90, 150, 210, 270, 330, 390, 450, 510, 570, and 630 meters.
2. We then performed additive stepwise variable selection with a Random Forest model to find the set of variables that resulted in a Random Forest with the highest R-squared between the field survey-based terrestrial passability score and the out-of-bag prediction from the model. Note, Random Forest is a non-parametric method that is effective at optimizing reliable predictions.
3. We fit similar models from the same suite of variables to estimate whether the crossing was a bridge or not.
4. Note, for the Connecticut River watershed Landscape Conservation Design pilot (CTR LCD) we used the predicted bridge status of the crossing to assign the mean aquatic passability score of crossings with the same status from the surveyed crossings to the unsurveyed crossings. Thus, all unsurveyed crossings predicted to be bridges were assigned the mean passability of the surveyed bridges, and all unsurveyed crossings predicted not to be bridges (including, e.g., culverts, fords, open-bottom arches) were assigned the mean passability of the surveyed crossing there were not bridges. However, for the Northeast regional product that we are distributing, the aquatic barrier scores reflect the predicted passability scores from the Random Forest model.
5. Lastly, the aquatic barrier score for unsurveyed road-stream crossings was given as the complement of the aquatic passability score (i.e., 1 - passability).

GIS metadata

This data product is distributed as a geoTIFF raster (30 m cells). The cell value contain terrestrial barrier scores, ranging from 0 (all cells not mapped as roads or railroads) to 5 (maximum barrier score; i.e., likely to be relatively impassable for most terrestrial organisms). This data product can be found at McGarigal et al (2017).

Literature Cited

McGarigal K, Compton BW, Plunkett EB, DeLuca WV, and Grand J. 2017. Designing sustainable landscapes products, including technical documentation and data products. https://scholarworks.umass.edu/designing_sustainable_landscapes/

Appendix

The following is a detailed description of the process for filtering the crossing records in the source database obtained from NAACC in order to include only those records and unique surveys that we could reliably associate with one of our derived road-stream crossings.

We began with the source data from NAACC (https://www.streamcontinuity.org/cdb2) containing 11,754 records for 10,332 surveys of 9,473 unique crossings.

1. We dropped duplicated records (probably due to the crossing having multiple structures each with its own line in the data export), resulting in dropping 1,422 duplicated records, leaving 10,332 records for 10,332 unique surveys of 9,473 unique crossings.
2. We dropped 14 records that were on a list of "bad" records provided by Scott Jackson, leaving 10,318 records for 10,318 unique surveys of 9,467 unique crossings.
3. We dropped surveys where the GPS location was greater than 200 meters from the crossing location (GPS is a field measure), leaving 10,017 records for 10,017 unique surveys of 9,210 unique crossings.
4. We dropped records with missing location data, leaving 9,283 records for 9,283 unique surveys of 8,484 unique crossings.
5. We dropped records where either the aquatic or terrestrial crossing scores (described in DSL_documentation_tbarriers_abstract.pdf) were NA (usually it was both), leaving 8,904 records of 8,904 unique surveys for 8,114 unique crossings.
6. We dropped records with duplicate crossing codes (repeat surveys of the same crossing), keeping the most recent survey, leaving 8,114 records of 8,114 unique surveys for 8,114 unique crossings.
7. We dropped crossings that were greater than 30 m (or 60 m in Vermont) from our derived road-stream crossing locations, leaving 6,832 crossings. Note, the threshold was higher for crossings in VT because the alignment between our road-stream crossing points and the crossing database locations was worse in VT. In all other states, the records tend to either be on top of each other (a good match) or far apart (a mismatch). These threshold distances were decided based on visual inspection of histograms of the distance to the nearest-neighbor match.
8. We dropped 58 surveyed crossings that were matched to the same road-stream crossing as another, closer survey, leaving 6,774 unique crossing retained for fitting the random forest models and inclusion in our output.