NatureServe Landscape Condition Model

DRAFT JUNE 2009

A. Introduction

In developing ecological integrity assessments, we can address attributes of the ecosystem itself or the stressors acting on those attributes. For ecosystems themselves, we want to identify a core set of metrics that best distinguish a highly impacted or degraded state from a relatively unimpaired or intact state, based on assessing the major ecological attributes. Metrics may be based either on characteristics that typify a particular ecosystem or attributes that change predictably in response to anthropogenic stress.

Second, we need to identify attributes that reflect the level of stressors that may be impacting the condition of the system, and which may be driving changes in these ecological attributes. Where we can develop a correlation between these two sets of attributes, we can develop a predictive model of how stressors impact the ecological integrity of the system. In this way, indicators from the first approach will indicate the magnitude of key stressors acting upon the system and increase our understanding of relationships between stressors and effects (Tierney et al. 2009).

There are growing sets of information on various kinds of stressors that impact ecosystems. Danz et al. (2007) noted that "Integrated, quantitative expressions of anthropogenic stress over large geographic regions can be valuable tools in environmental research and management." When they take the form of a map, or spatial model, these tools initially characterize ecological conditions on the ground; from highly disturbed to apparently unaltered conditions. They can be particularly helpful for screening candidate reference sites; i.e., a set of sites where anthropogenic stressors range from low to high. Ecological condition of reference sites are further characterized to determine how ecological attributes are responding to apparent stressors. This knowledge may then apply in other similar sites.

Anthropogenic stressors come in many forms, from regional patterns of acid deposition or climate-induced ecosystem change, to local-scale patterns in agricultural drainage ditches and tiles, point-source pollution, land-conversion, and transportation corridors, among others. To be effective, a landscape condition model needs to incorporate multiple stressors, their varying individual intensities, the combined and cumulative effect of those stressors, and if possible, some measure of distance away from each stressor where negative effects remain likely. Since our knowledge of natural ecosystems is varied and often limited, a primary challenge is to identify those stressors that likely have the most degrading effects on ecosystems or species of interest. A second challenge is to acquire mapped information that realistically portrays those stressors. In addition, there are tradeoffs in costs, complexity, the often varying spatial resolutions in available maps, and the variable ways stressors operate across diverse land and waterscapes. Typically, expert knowledge forms the basis of stressor selection, and relative weighting. Once models are developed, they may be calibrated with field measurements. Developing empirical relationships between stress variables and ecological response variables is a key to providing insights into how human activities impact ecological condition (Danz et al. 2007).

B. Landscape Condition Model

There are two primary uses for NatureServe's landscape condition model: 1) *to map the predicted ecological conditions one would encounter in the field, based on apparent stressors present across the landscape of interest*, and 2) *facilitate repeated predictions of ecological condition within the same landscape over time, or given alternative land use proposals.* Maps predicting relative ecological condition can provide a screening tool for gauging anthropogenic stress in locations including any mapped point or polygon. Repeated predictions of ecological condition assist with evaluating likely effects of changes in overlapping land uses on the condition of the landscape for an element or group of elements. This can provide a powerful tool understanding cumulative effects of land use change over time and/or for modeling environmental restoration options. The landscape condition model is integrated into NatureServe's Vista software (NatureServe 2009).

C. METHODS

Here we focus on the methods for developing a landscape condition model. This model is needed as a predictive tool to screen candidate reference sites. The model needs to provide a set of sites that contain the range of ecological condition (perhaps categorized by High, Moderate, or Low Condition). At the outset, we use a general set of stressors, presuming that they are relevant to what's affecting condition on the ground. Ultimately, we would like to calibrate the model with a robust sampling of field observations so that all model inputs and settings most efficiently reflect field conditions.

C.1. Study Area

The study area is the conterminous U.S, but NatureServe is working with partners to develop regional models and groups of elements models (e.g., wetlands).

C.2. Selected Stressors

For this national model, we selected a limited set of stress-inducing land use classes for which we have nationally consistent coverage. Our aim here is to characterize the primary local scale stressors. We have not attempted to factor in regional stressors, such as air pollutants or climate change. Stressors are organized into thematic groupings of Transportation, Urban and Industrial Development, and Managed & Modified Land Cover.

Transportation features, derived from ESRI StreetMap data circa 2006, depict roads of four distinct sizes and expected traffic volume. These data provide a practical measure of human population centers and primary transportation networks that link those centers. Ecological stress induced by built infrastructure (through habitat loss, fragmentation, altered ecological processes, etc.) are well known.

As a compliment to Transportation infrastructure, Urban and Industrial Development includes industrial (e.g., mines) and built infrastructure across a range of densities, from high density urban and industrial zones, to suburban residential development, to exurban residential and urban open spaces (golf courses, for outdoor recreation. These data were derived from national land cover data through combined efforts of US Geological Survey (National Land Cover and Gap Analysis Programs) and the inter-agency LANDFIRE effort.

The third category, Managed and Modified Land Cover, includes the gradient of land cover types that reflect land use stressors at varying intensities. Again, national data from USGS and LANDFIRE provide a consistent depiction of these varying land cover classes, from intensive (cultivated and/or irrigated) agriculture, pasture & hay fields, vineyards and timber tree plantations, various forms of introduced non-native vegetation in upland and wetland environments, and finally, areas where native vegetation predominates, but modifications have clearly taken place. These modifications include recently logged areas, or areas that have seen historic conversion, but have recovered some combination of mainly native vegetation (old fields, 'off-site' hardwoods and conifers in many southeastern forest, etc.).

Table 1. Stressors selected and mapped for modeling landscape condition nationally.

Theme	Source	Spatial Resolution
Transportation		
Primary Highways with limited access	ESRI® Data & Maps: StreetMap™ Series issue: 2006 United States	1:100,000
Primary Highways without limited access	ESRI® Data & Maps: StreetMap™ Series issue: 2006 United States	1:100,000
Secondary and connecting roads	ESRI® Data & Maps: StreetMap™ Series issue: 2006 United States	1:100,000
Local, neighborhood and connecting roads	ESRI® Data & Maps: StreetMap™ Series issue: 2006 United States	1:100,000
Urban and Industrial Development		
High Density Developed	National Land Cover Data/ LANDFIRE Existing Vegetation 2001-2003 United States	30m pixel/ 1:100,000
Medium Density Development	National Land Cover Data/ LANDFIRE Existing Vegetation 2001-2003 United States	30m pixel/ 1:100,000
Low Density Development	National Land Cover Data/ LANDFIRE Existing Vegetation 2001-2003 United States	30m pixel/ 1:100,000
Managed & Modified Land Cover		
Cultivated Agriculture	National Land Cover Data/ LANDFIRE Existing Vegetation/Gap Analysis Program 2001-2003 United States	30m pixel/ 1:100,000
Pasture & Hay	National Land Cover Data/ LANDFIRE Existing Vegetation/Gap Analysis Program 2001-2003 United States	30m pixel/ 1:100,000
Managed Tree Plantations	National Land Cover Data/ LANDFIRE Existing Vegetation/Gap Analysis Program 2001-2003 United States	30m pixel/ 1:100,000
Introduced Upland Herbaceous	National Land Cover Data/ LANDFIRE Existing Vegetation/Gap Analysis Program 2001-2003 United States	30m pixel/ 1:100,000
Introduced Wetland Vegetation	National Land Cover Data/ LANDFIRE Existing Vegetation/Gap Analysis Program 2001-2003 United States	30m pixel/ 1:100,000
Introduced Tree & Shrub	National Land Cover Data/ LANDFIRE Existing Vegetation/Gap Analysis Program 2001-2003 United States	30m pixel/ 1:100,000
Recently Logged	National Land Cover Data/ LANDFIRE Existing Vegetation/Gap Analysis Program 2001-2003 United States	30m pixel/ 1:100,000
Native Vegetation with Introduced Species	National Land Cover Data/ LANDFIRE Existing Vegetation/Gap Analysis Program 2001-2003 United States	30m pixel/ 1:100,000
Ruderal Forest & Upland	National Land Cover Data/ LANDFIRE Existing Vegetation/Gap Analysis Program 2001-2003 United States	30m pixel/ 1:100,000

C.3. Model Parameters

Relative Site Intensity

Each land cover category was given a **relative site intensity** score, between 0.0 and 1.0, to represent our assumptions of stress induced by each land cover type on terrestrial ecological systems and habitat for native species. As depicted in Table 2, a relative site intensity score that is close to 0.0 indicates our assumption that this land cover induces very high levels of stress on local ecosystems. Scores closer to 1.0 are assumed to induce some level of stress, but that stress is much more limited. Generally, each land cover category is listed within these generalized categories of assumed stress, but their individual numerical scores were used in modeling. Typically, only one land cover occurs at each pixel, but where more than one can occur, the lowest score is applied (i.e., the highest-impact use determines the pixel value). Therefore, in instances where e.g., a roads layer is distinct from the land cover layer, the roads layer could indicate a 0.05 score, and the land cover layer would also provide a 0.05 score for 'high intensity developed.' Only one value of 0.05 would apply to that pixel.

Table 2. Relative Site Intensity scores used for modeling landscape condition nationally.

Theme	Relative Site Intensity (0.0-1.0)	Relative Stress at Point of Impact
Transportation		
Primary Highways with limited access	0.05	Very High
Primary Highways without limited access	0.05	Very High
Secondary and connecting roads	0.2	High
Local, neighborhood and connecting roads	0.5	Medium
Urban and Industrial Development		
High Density Developed	0.05	Very High
Medium Density Development	0.5	Medium
Low Density Development	0.6	Medium
Managed & Modified Land Cover		
Cultivated Agriculture	0.3	High
Pasture & Hay	0.9	Low
Managed Tree Plantations	0.8	Low
Introduced Upland Herbaceous	0.5	Medium
Introduced Wetland Vegetation	0.3	High
Introduced Tree & Shrub	0.5	Medium
Recently Logged	0.9	Low
Native Vegetation with Introduced Species	0.9	Low
Ruderal Forest & Upland Old Field	0.9	Low

The site intensity scores attempt to represent the relative degree of ecological stress induced locally in the immediate area where the land cover occurs. We treat distance effects surrounding the impacting land cover as a separate component of the model. However, the spatial model will calculate an initial distance effect that varies with the site intensity score of the model. Figure 1 illustrates this initial distance effect resulting solely from the site intensity score of each land cover. This effect decays to zero within distances ranging from 200-800 meters from the impacting land cover.

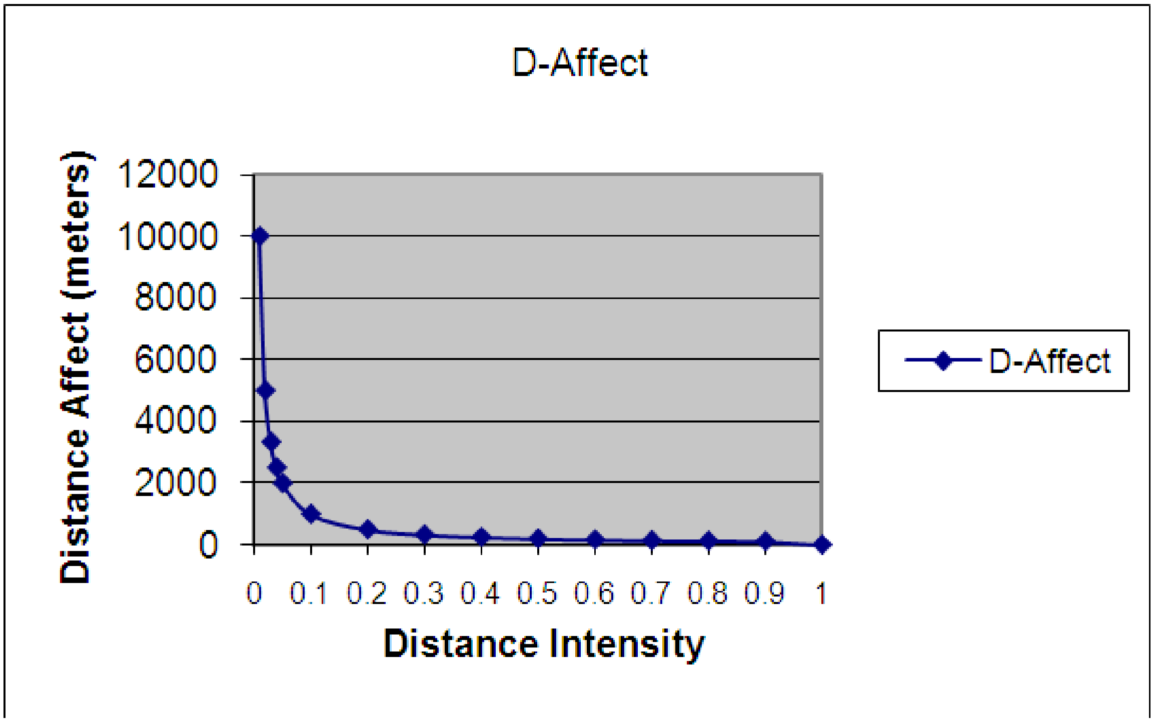

Figure 1. Default distance effect of site intensity score on initial condition of land cover type. Here site intensity score is labeled as no Wt (score of 1.0), Wt 0.5, Wt 0.05, Wt 0.005.

Distance Decay Function

Each land cover category was also given a **distance decay function**, also scaled between 0.0 and 1.0, to represent our assumptions of decreasing stress-effects of each land cover with distance away from each impacting feature. The function changes the slope of the initial site intensity curve (Fig. 1) by pushing the terminus of the curve further from the land cover source causing a more gradual decay to occur. When combined with the site intensity, the decay function may be heavily modified to represent land cover types such as 4-lane highways where the assumed stress at the site is high and the distance effect from the feature is long. So, if the site intensity score is low – for high stress (e.g., 0.3) and the distance decay function is relatively high (e.g., 1.0), the resulting spatial model would depict the circumstance where the effect of the high stress land cover is expected to decrease rapidly over short distances. Conversely, if for the same site intensity score (again, 0.3) was given a low distance decay function (also 0.3) the expected distance effect of that land cover would extend out over a greater distance.

As depicted in Table 3, the distance intensity score determines the rate of decay in condition values for each layer to a given distance where that effect reaches zero. Table 3 serves as a basic guide to developers of these models, especially where documented experience has indicated a specific distance where effects can be presumed to have reached zero, such as studies of effects of nest parasites on forest interior birds, with specific distances have been recorded where this stress dissipates to zero.

Table 3. Distance Decay functions and the maximum distance where effects reach zero.

D-Intensity Score	Distance Decay to Zero (meters)	Km
1	0	0.0
0.9	111	0.1
0.8	125	0.1
0.7	143	0.1
0.6	167	0.2
0.5	200	0.2
0.4	250	0.3
0.3	333	0.3
0.2	500	0.5
0.1	1,000	1.0
0.05	2,000	2.0
0.04	2,500	2.5
0.03	3,333	3.3
0.02	5,000	5.0
0.01	10,000	10.0
0.003	33,333	33.3
0.004	25,000	25.0
0.005	20,000	20.0
0.006	16,667	16.7
0.007	14,286	14.3
0.008	12,500	12.5
0.009	11,111	11.1
0.002	50,000	50.0
0.001	100,000	100.0

Distance decay scores used in the national model are listed in Table 4. Again, a distance decay function that is close to 0.0 indicates our assumption that this land use effects ecological condition for long distances away for the point of impact. Scores closer to 1.0 are assumed to induce some level of stress, but that effect is dissipated to negligible levels very quickly with distance.

Table 4. Distance Decay Functions used for modeling landscape condition nationally.

Theme	Distance Decay Function (0.0-1.0)
Transportation	
Primary Highways with limited access	0.05
Primary Highways without limited access	0.05
Secondary and connecting roads	0.2
Local, neighborhood and connecting roads	0.5
Urban and Industrial Development	
High Density Developed	0.05
Medium Density Development	0.5
Low Density Development	0.5
Managed & Modified Land Cover	
Cultivated Agriculture	0.5
Pasture & Hay	0.9
Managed Tree Plantations	0.5
Introduced Upland grass & forb	0.5
Introduced Wetland Vegetation	0.8
Introduced Tree & Shrub	0.5
Recently Logged	0.5
Native Vegetation with Introduced	1.0
Ruderal Forest & Upland Old Field	1.0

For a land cover type to be included, the user must set intensity values between >0 and 1. If the value is set to 1, the land cover will be treated as a stressor included in the landscape condition model, but no weight modifiers will be applied to the land cover type.

The overall intensity at a pixel unit represents the lowest value of all the land cover types which may overlap at a single pixel. Because this model works in an additive progression with the final summary normalized against the maximum value of 1.0, the effect of any one distance decay score could be effected by the inclusion of other land uses with less weight.

The Boost Factor is a power function optionally applied to the final condition model to adjust the distribution of the model results. The option defaults to a value of 1 and it is recommended that the user only adjust this value with substantial understanding of how the results will be transformed. No boost factor was applied to the national landscape condition model reported here.

C.4. Results

We use an expert-based judgment to compile the layers and create an overall Landscape Condition Model for the conterminous United States. Figures 2 and 3 display the results of this national model; with figure 3 indicating a pair-wise comparison of current land cover and the resulting landscape condition model for a local area. Blue colors indicate landscapes modeled to high landscape condition. Orange to red colors indicate apparently low landscape condition.

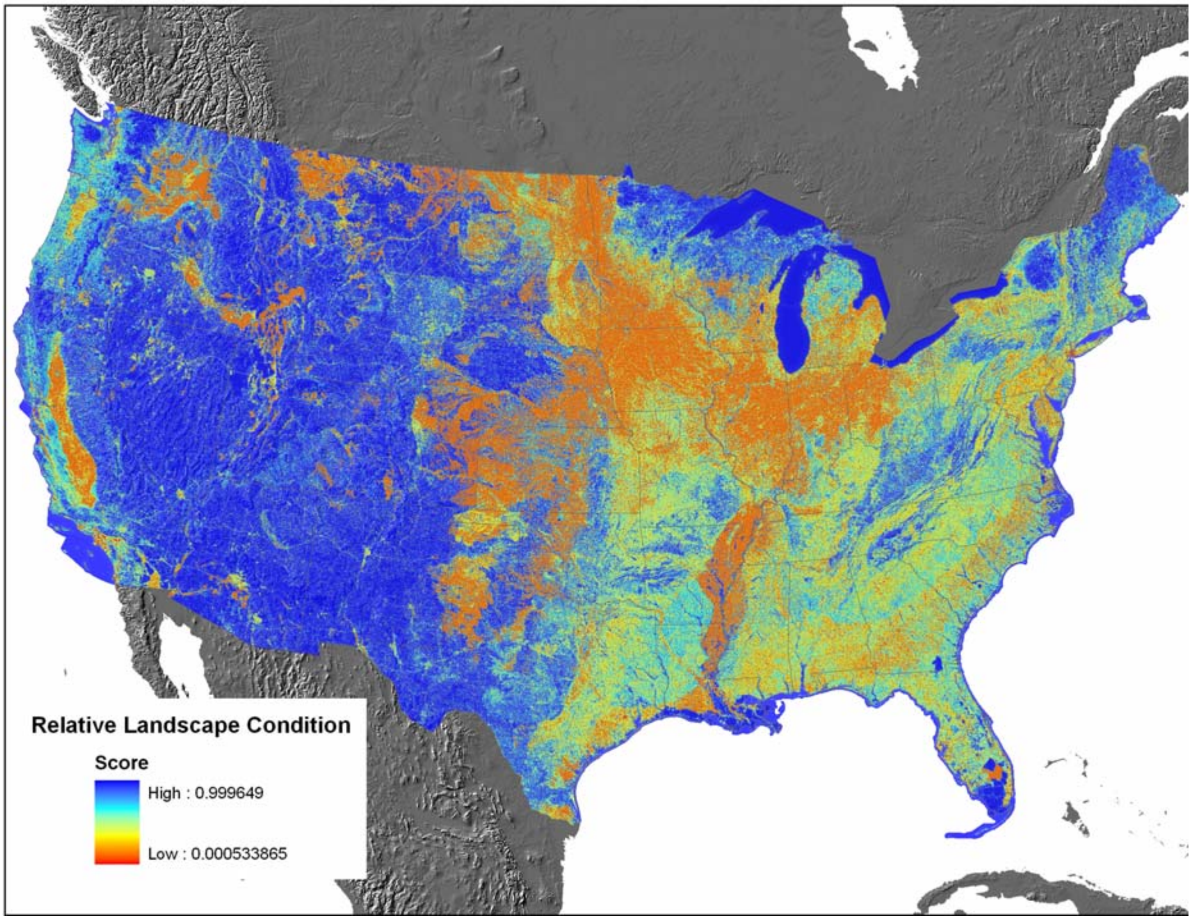

Figure 2. Landscape condition model for the conterminous United States.

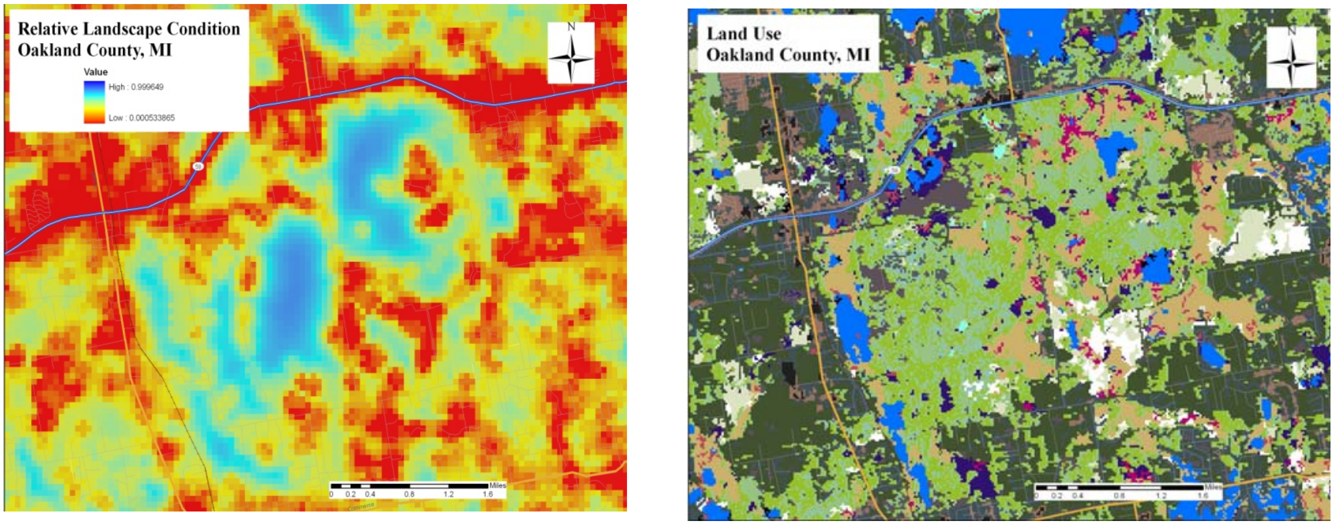

Figure 3. Landscape condition model (left) and current land cover (right) for a several square mile location in southern Michigan.

C.5 Model Evaluation

The interpretation of what constitutes a poor landscape condition for an individual ecosystem or habitat type is strictly up to the user's interpretation of how land uses should affect key ecological processes on and off site. However, for setting condition thresholds, field -observed condition and viability standards for specific ecosystems and habitats can be informative. Figure 4 includes box plots summarizing landscape condition scores relative to over two thousand field documented occurrences for at-risk species throughout the Pacific Northwest United States. Generalized relations between landscape condition scores and these field observations are apparent. These results provide some indication of threshold values for the landscape condition model that one might choose if the desire is to identify all landscapes likely to support "fair" "good/very good" condition occurrences of natural community types of habitat types. For instance, a user's goal may be to locate potential element occurrences with EO Rank values of B or better. As such, the condition value threshold would be set to the equivalent of about 0.8.

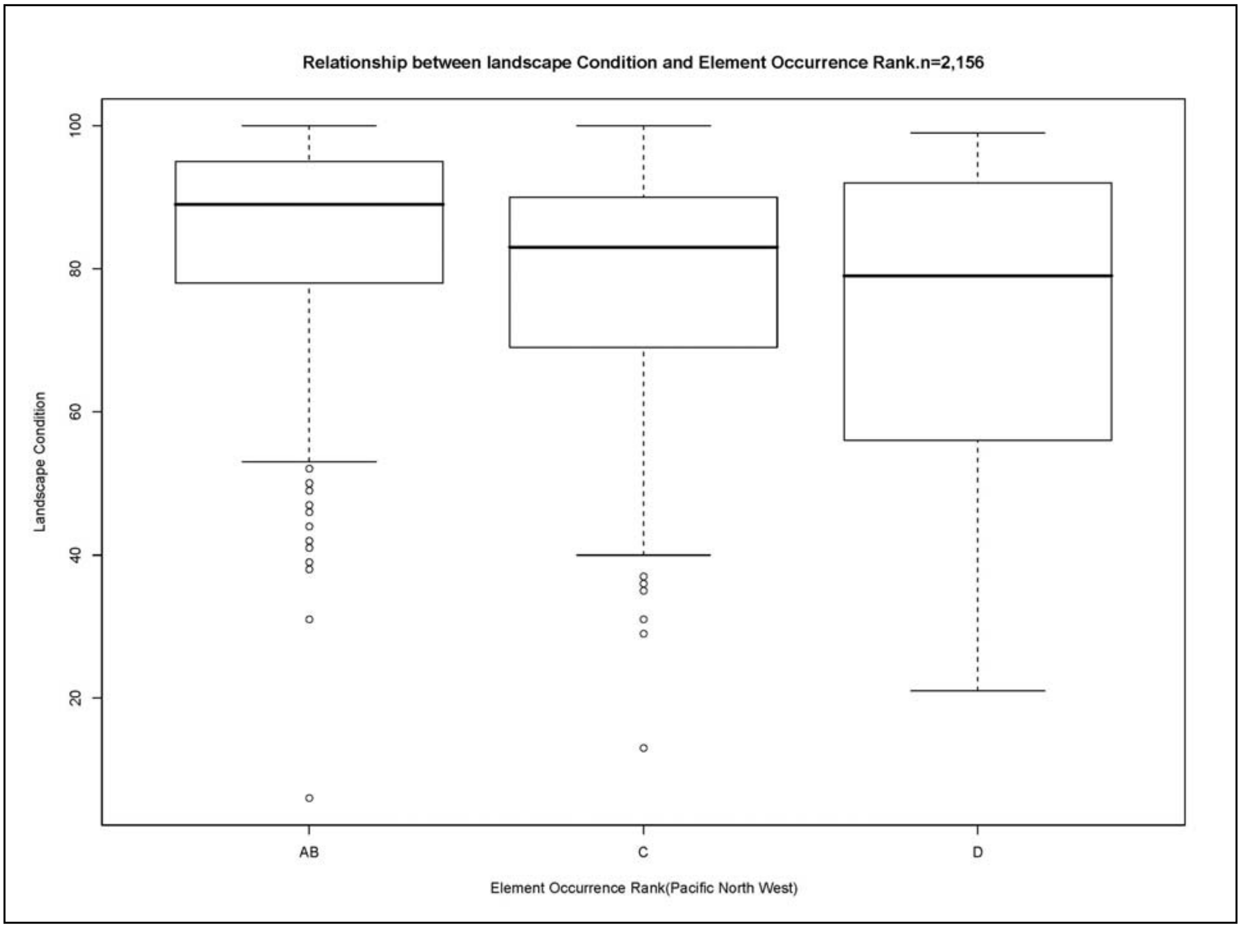

Figure 4. Interpretation of landscape condition thresholds using Ecological Integrity (Element Occurrence Rank) values from Natural Heritage Program databases.

C.6. Limitations

The concept of landscape condition modeling is highly simplified resulting in relative indices of condition that take into account a fairly narrow set of considerations. Although experts building and documenting the model may consider a number of factors in assigning site and distance intensity weights, the model does not explicitly address issues such as impacts on species mobility, demographics, habitat connectivity among multiple resources, etc. Other modeling tools exist that consider some of these issues when knowledge, time, and funding exist to address them.

D. REFERENCES

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