Designing Sustainable Landscapes: Glossary

A project of the University of Massachusetts Landscape Ecology Lab

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1 Purpose

The purpose of this document is to provide a glossary of key terms and concepts used in the *Designing Sustainable Landscapes* (DSL) project (McGarigal et al 2017) that will facilitate communication and understanding among users. We recognize that many of the terms and concepts included in this glossary have been defined inconsistently in the literature and thus have been interpreted and used inconsistently in practice, leading to confusion and misunderstanding. Our intent is to provide a clear definition of each term/concept based on our understanding and interpretation and, more importantly, its application in the DSL project.

2 Glossary

Adaptive capacity. The capacity of a **site** to adapt to a changing environment (e.g., as driven by climate change); it encompasses the ability of an ecosystem subject to disturbance and change to reorganize and renew itself; i.e., the degree to which the system is capable of self-organization (versus a lack of organization, or organization forced by external factors), and how much it expresses a capacity for learning and adaptation (Carpenter et al. 2001, Elmqvist et al. 2003). Adaptive capacity reflects the potential for adaptation via movement to and from a site in order to track favorable conditions as they change over the long term under non-equilibrium dynamics, and thus is only applicable in applications involving landscape change over time. Adaptive capacity is an intrinsic attribute of a site that reflects the **ecological integrity** of the site itself and thus, by extension, confers ecological integrity to the landscape as a whole. Adaptive capacity is measured using a single core **metric**: adaptive capacity.

Climate niche (CN). The climatic conditions that best predict the species' geographic distribution based solely on climate variables. The climate niche is measured as an index of the species' relative probability of occurrence and is based on the combination of climate variables that best explain the species' geographic distribution in 2010. Note, the CN index does not account for habitat and other biogeographic factors influencing a species' distribution.

Conductance, conductance index. The degree to which a site impedes or facilitates ecological flows between other sites; in other words, to what extent does a focal cell play a role in connectivity between point A and point B, or to what degree does a focal cell function as a thruway for flows between point A and point B. The conductance index measures the degree to which a focal cell functions as a linkage between neighboring cells (i.e., **local conductance**) or between nearby conservation nodes (i.e., **regional conductance**); it depends on the intervening **landscape resistance** and the size and proximity of nearby nodes in the case of regional conductance. The conductance index is applied to a particular landscape "as is," without assessing contingent effects on **connectivity**, as is done in a **critical linkage** analysis.

Contingent units. Sites (defined either automatically or by the user) where landscape resistance may change in the future (e.g., parcels of land that may be developed, or roads that may be mitigated by passage structures). These are the elements evaluated in a **critical linkage** analysis.

Connectivity, landscape connectivity. The functional connectedness of the landscape as perceived by one or more focal organisms or ecological process; that is, the propensity of the landscape to facilitate or impede relevant ecological flows. Landscape connectivity reflects the interaction of ecological flows (e.g., movement of organisms) with the physical continuity or structural connectedness of the landscape. Note, connectivity is a multi-scaled, multi-faceted concept that can be considered from many different perspectives, and thus measured in many different ways. In particular, connectivity refers to the ability to conduct flows both locally (**local connectivity**) and regionally (**regional connectivity**) and, as such, it is an important component of **resiliency** and **adaptive capacity**.

Continuity, landscape continuity. The physical continuity or structural connectedness of the landscape. Note, continuity is a physical attribute of the landscape; it is not defined from the perspective of any particular organism or ecological process as in the concept of **connectivity**.

Conservation feature, conservation element. An ecological entity, such as an ecological system or species, that is the focus of conservation efforts. In the context of **landscape conservation design**, conservation features provide the focus for establishing **conservation targets** and the design of a **conservation network**.

Conservation target. A quantitative measure associated with a **conservation feature** (or element), such as the total area of the feature to be protected, managed or restored. In the context of **landscape conservation design**, conservation targets are established for conservation features and provide the quantitative basis for establishing a **core area network**.

Core area. A designated area possessing high ecological value (typically based on **ecological integrity** of focal ecological systems and/or **landscape climate capability** of focal species), including a variable width buffer zone around the locations of high value so as to prevent future degradation, within which conservation actions (e.g., land protection, land management, ecological restoration) are taken for the primary purpose of conserving biodiversity; one of the major spatial components in our **landscape conservation design** framework.

Core area network. A collection of conservation **core areas** loosely connected via **linkages** (e.g., **corridors**) that collectively is designed to capture the areas of greatest ecological importance within which conservation actions (e.g., land protection, land management, ecological restoration) are taken for the primary purpose of conserving biodiversity; one of the major spatial components in our **landscape conservation design** framework.

Connector, corridor, **conservation corridor**. A designated area serving as a **link** between designated **core areas** within which conservation actions (e.g., land protection, land management, ecological restoration) are taken for the primary purpose of facilitating connectivity between core areas; as used in our **landscape conservation design** framework corridors are not delineated as discrete entities but rather as fuzzy features described using measures of **regional conductance**, **irreplaceability** and **vulnerability**.

Critical linkage. A **unit** that has great leverage on **connectivity**, e.g., a parcel (or set of parcels, not necessarily contiguous) that would seriously disrupt connectivity if developed. A critical linkage analysis assesses the relative importance of many units (and combinations of units) for connectivity.

Disturbance. A relatively discrete event (natural or anthropogenic) in time that disrupts ecosystem, community, or population structure and changes resources, substrate availability, or the physical environment, including both destructive, catastrophic events as well as less notable, natural environmental fluctuations. Typically, a disturbance causes a significant change in the system under consideration.

Diversity, **ecosystem diversity**. The variety and abundance of **ecological systems** (or **ecological settings**) represented within a user-specified area. Ecosystem diversity is a collective property of area encompassing multiple sites (e.g., undeveloped lands within the landscape) and is not a measurable site attribute, since a site has a single ecological system or ecological setting. Ecosystem diversity is measured using a single core **metric**: diversity.

Ecological condition. The current biophysical condition of an ecosystem within its **ecological setting**, in terms of its composition, structure and function. Ecological condition is closely related to ecological setting. Whereas ecological setting refers to the biophysical characteristics that structure ecosystems over the long term and serve to define and distinguish ecosystems, especially in the absence of anthropogenic **stressors**, ecological condition refers to the current biophysical condition of the ecosystem in reference to its natural range of variability. Importantly, the current ecological condition can be forced outside its natural range of variability by anthropogenic stressors. In addition, ecological condition is tightly coupled with **ecological integrity**; both affect and are affected by the other. Specifically, the impact of a stressor on current ecological condition is influenced by the system's ecological integrity, because a system with high integrity has greater capacity to absorb stress without undergoing transformational change. Similarly, the current condition of an ecosystem, as influenced by its immediate response to stressors, will ultimately influence the system's ecological integrity, since adversely modified conditions (e.g., removal of keystone species) will serve to degrade the long-term ecological integrity of the system. Thus, there is an implicit assumption that "condition" and "integrity" are highly interdependent, and therefore that "condition" is a reasonable, albeit noisy, short-term surrogate for "ecological integrity". This assumption is necessary because ecological integrity is not measurable (in a practical sense), whereas ecological condition is.

Ecological distance. Distance between two points in (multivariate) **ecological setting** space. Note, this is an aspatial concept; it is the distance between sites in a multidimensional ecological (abstract) space (where each dimension represents a different ecological variable) rather than geographical space.

Ecological integrity. The ability of an area (e.g., local site or landscape) to sustain important **ecological functions** over the long term; in particular, the ability to support biodiversity and the ecosystem processes necessary to sustain biodiversity over the long term. Note, here we emphasize the maintenance of ecological *functions*, rather than the maintenance of ecosystem *composition* and *structure*. By focusing on functions rather than composition and structure, we are implicitly acknowledging that the ecological composition and structure of an area will change over time in response to changes in the environment (e.g., via climate changes), and this change is deemed acceptable so long as the important ecological functions are maintained. This definition contrasts somewhat with other published definitions, for example that of Karr and Dudley (1981), who define ecological integrity as "the ability of an ecosystem to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of natural habitats within a region...the summation of chemical, physical and biological integrity can be equated with ecological integrity. A system possessing integrity can withstand, and recover from, most perturbations imposed by natural environmental processes, as well as many major disruptions induced by man". Here, the emphasis is on maintaining both composition and function within some natural range of variability. We believe that defining the "natural" condition is problematic -- what is "natural" after all, given the long history of anthropogenic changes to the landscape -- and that maintaining composition over the long term does not adequately reflect the expected evolution of landscapes (in composition and structure) in response to inevitable environmental change. Importantly, all definitions of integrity either implicitly or explicitly suggest that an integral system is also resilient to disturbance and stress; they differ largely in whether **resiliency** is defined in terms of ecosystem function or more broadly in terms of ecosystem composition, structure and function. Note, because ecosystems (sites) vary in their resiliency to stress (e.g., alpine ecosystems are much less resilient to trampling and soil compaction than low-elevation forests), they also vary in their inherent **ecological integrity**. Moreover, while ecological integrity is deemed essential for ecosystem/landscape sustainability, it is effectively impossible to quantify directly (as far as we are concerned). Instead, we measure ecological integrity indirectly using a broad suite of **landscape metrics**.

Ecological function. The natural ecological processes that occur within an ecosystem. Natural processes, in turn, are the result of complex interactions between biotic (living organisms) and abiotic (chemical and physical) components of ecosystems through the universal driving forces of matter and energy (De Groot et al. 2002). Ecological function is also sometimes defined from an anthropocentric perspective as "the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly" (De Groot 1992). However, we prefer to view ecological functions as the basic ecological processes that regulate the composition and structure of ecosystems over time, without any attention to the direct or indirect benefit to humans. Note, with our definition, ecological functions and ecological processes are effectively synonymous, and thus we used these terms interchangeably.

Ecological setting. The principal biophysical characteristics of a site (e.g., elevation, temperature, solar gain, wetness, flow velocity, lithology, etc.) that strongly influence the composition, structure and function of the ecosystem and serve to describe and distinguish it ecologically from other sites. Importantly, the ecological setting of an ecosystem includes the range of natural variation in biophysical states that characterize its distribution in space and time. As noted above, ecological setting and **ecological condition** are closely related; the former referring to the long-term range of variability in biophysical states of a site, and the latter referring to the current biophysical state of a site. Thus, the ecological condition is simply the current state of the ecological setting. The current ecological condition thus varies in response to natural and anthropogenic disturbances and other ecological processes, and anthropogenic **stressors** can cause the current ecological condition to move outside its range of natural variability for a site. Moreover, persistent departures in ecological condition, for example as might be caused by climate change and anthropogenic land use, can lead to permanent changes in ecological setting or settings that are constantly changing at ecological time frames. Lastly, the ecological setting of a site (or ecosystem) influences its **ecological integrity**, because some settings are less resilient to stress than others (e.g., an isolated wetland is less resilient to species loss than a well-connected wetland because the latter has better opportunities for recolonization of constituent species).

Ecological systems. As defined by NatureServe (http://www.natureserve.org/publications/usEcologicalsystems.jsp), "Ecological systems represent recurring groups of biological communities that are found in similar physical environments and are influenced by similar dynamic ecological processes, such as fire or flooding. They are intended to provide a classification unit that is readily mappable, often from remote imagery, and readily identifiable by conservation and resource managers in the field... A given system will typically manifest itself in a landscape at intermediate geographic scales of tens to thousands of hectares and will persist for 50 or more years. This temporal scale allows typical successional dynamics to be integrated into the concept of each unit." Importantly, ecological systems serve as the basic coarse filter **conservation feature** and also play a important role in defining suitable habitat for most focal species.

Focal species. A species serving as a focus for conservation actions. A focal species can be targeted for any number of reasons owing to their designated role or value as a representative or surrogate, indicator, sentinel, umbrella, keystone, threatened or endangered, flagship, game, or pest.

Habitat capability (HC). The ability of the environment to provide the local resources (e.g., food and cover) needed for survival and reproduction in sufficient *quantity*, *quality* and *accessibility* to meet the life history requirements of individuals and local populations. Note, we distinguish habitat "capability" from the more conventional use of "suitability" on the basis of including the "accessibility" of resources. In addition, the modeled HC index is based solely on habitat variables and does account for climate and other biogeographic factors influencing a species' distribution.

Intactness. The freedom from human impairment (anthropogenic **stressors**), sometimes referred to "naturalness"; it is an intrinsic attribute of a site that contributes to the **ecological integrity** of the site itself and thus, by extension, confers ecological integrity to the landscape as a whole. Intactness is measured using a weighted linear combination of a broad suite of stressor **metrics**.

Landscape capability (LC). The ability of the landscape to provide the environment (e.,g., climate conditions) and the local resources (e.g., food and cover) needed for survival and reproduction (i.e., habitat) in sufficient quantity, quality and accessibility to meet the life history requirements of individuals and local populations. Note, LC combines the influence of habitat capability, climate suitability and other unmeasured biogeographic factors (e.g., interspecific interactions, disease, persecution, etc.) into a single index that reflects where the species is most likely to occur, but it is not an estimate of the species' true probability of occurrence.

Landscape conservation design (LCD). A coordinated suite of conservation actions within a designated spatial and temporal extent intended to modify the landscape pattern for the purpose of conserving biodiversity while recognizing socio-cultural and economic constraints. Landscape design was defined by Nassauer and Opdam (2008) "as any change of landscape pattern for the purpose of sustainably providing ecosystem services while recognizably meeting societal needs and respecting societal values". However, we prefer to emphasize conserving biodiversity for biodiversity sake rather than the more anthropocentric emphasis of providing ecosystem services.

Landscape structure. The composition and configuration of relevant features or elements over some spatial extent. Composition refers to the number and variety of landscape elements (and is aspatial), whereas configuration refers to the spatial arrangement, position and juxtaposition of landscape elements. The elements, or thematic content of the landscape, must be defined in a manner and at a scale that is meaningful to the phenomenon under consideration. The classic and most familiar framework for landscape structure is the patch mosaic (typically of land cover types), but there are many other models of landscape structure.

Least-cost path. The shortest path through a **resistant landscape** between two points. The least-cost path between a focal cell and any other point in the landscape is encoded in a **resistant kernel**.

Link, **linkage**. A generic term for the connection between designated **nodes** (e.g., **core areas**); the **regional connectivity** analysis assesses connectivity among nodes that are connected via links. Links may correspond to mapped areas of the landscape (e.g., fuzzy corridors), but they may also be abstract connections without any specific geographic translation, for example as used in a schematic representation of a conservation network.

Local conductance, local conductance index. The degree to which a site (cell) impedes or facilitates ecological flows between other sites within a local ecological neighborhood independent of any designated **core area network**. Local conductance depends on the **landscape resistance** in the neighborhood of the focal cell, which is a function of the ecological similarity between cells, and is a cell-based measure of conductance computed for every cell.

Local connectivity. The spatial scale at which **landscape structure** influences the movement of individuals across the landscape; i.e. the scale at which the dominant organisms interact directly with the landscape via demographic processes such as home range movements and dispersal. This is the landscape context that an individual organism might experience during its lifetime. In general, the spatial scale for a local connectivity assessment is in the range of several kilometers, but it remains a flexible parameter. Local connectivity is measured using a **resistant kernel** in the **metric** connectedness (or aquatic connectedness).

Matrix, **landscape matrix**. The background of a landscape within which designated core areas, buffers and corridors exist as part of a designed landscape. Alternatively, in the context of landscape definition, the matrix is the landscape element that comprises the majority of the landscape, is thus well connected and, as such, has a dominant influence on landscape function; the matrix is one of the structural elements often recognized in a patch mosaic model of landscape structure.

Metric, landscape metric. A quantitative measure of landscape structure, including both *structural* metrics that pertain to the physical character of the landscape and *functional* metrics that pertain to how an organism or ecological process may interpret the physical properties of the landscape.

Node. A generic term for a contiguous area of conservation interest (e.g., **core area**); the **regional connectivity** analysis assesses connectivity among nodes. Nodes are typically heterogeneous in **ecological setting**, and they correspond to mapped areas of the landscape; they are not merely abstract points, even though they are often represented as such in schematic depictions of networks.

Path distance. Functional distance between two points on a map, taking into account **landscape resistance**. This is dependent on an integration of the physical geographic distance between the points and the **ecological distance** between the starting point and each intervening point along the particular path, typically either the **least-cost path** or a **random low-cost path**.

Prevalence. The <u>relative</u> probability of occurrence of a species based solely on the species' current distribution without explicitly accounting for habitat capability, climate suitability or other factors influencing a species' distribution. Note, the prevalence index is a proxy for the combined biographic factors influencing a species' probability of occurrence and is an attempt to account for the factors other than habitat capability and climate suitability that are influencing a species' current distribution. Prevalence is used in combination with habitat capability and climate niche to produce the landscape capability index for each species.

Probability of Connectivity (PC). The probability that an animal in a random **node** would be able to traverse the network to any other given node in the landscape (Saura and Pascual-Hortal, 2007). PC measures **regional connectivity** through a network of nodes and **links**. It ranges from near 0 (tiny disconnected nodes) to 1.0 (a single fully connected node filling the landscape). PC may be compared between two landscapes, resulting in **ΔPC**, which measures the improvement (positive ΔPC) or loss (negative ΔPC) in regional connectivity given changes in the landscape. ΔPC is the measure of node and link importance, and of the value of each potential **contingent unit**.

Random low-cost path (RLCP). A stochastic version of the **least-cost path** that randomizes steps in the **resistant kernel**. The resulting path is expected to be of (reasonably) low cost, but not optimal. RLCP parameters determine how much the path can be expected to deviate from optimal; by default, the directional probability at each step is proportional to the value of the resistant kernel in each direction. Typically many RLCPs are produced to assess the robustness of **connectivity** between two **nodes**, and to allow for **critical linkage** analysis.

Regional conductance. The degree to which a site (cell) impedes or facilitates ecological flows between two nearby conservation nodes (**core areas**) and thus contributes to regional connectivity of the conservation network. The regional conductance index measures the relative probability of ecological flow through cells between nearby designated conservation nodes; it depends on the size and proximity of the nearby nodes and the intervening **landscape resistance**, and is one of the major spatial components in our **landscape conservation design** framework.

Regional connectivity. The spatial scale at which **landscape structure** influences long-term ecological processes such as range expansion/contraction and gene flow; the scale exceeding that in which individual organisms directly interact with the landscape. At this scale, individuals generally do not interact with the landscape, but their offspring or their genes might over multiple generations. Consequently, there is no real upper limit on the regional scale; the longer the time frame, the broader the regional scale at which the landscape structure matters. Regional connectivity is measured using the metric **Probability of Connectivity (PC)**.

Regional irreplaceability. The degree to which a site (cell) is irreplaceable as a part of a pathway between two nearby conservation nodes (**core areas**). The regional irreplaceability index measures the proportion of the **random low cost paths** between two nearby nodes that pass through the focal cell; it reflects the degree to which there are alternative pathways between the conservation nodes and is not affected by the size or proximity (up to a certain threshold distance) of the nearby nodes (in contrast to **regional conductance**) is one of the major spatial components in our **landscape conservation design** framework.

Regional vulnerability. The relative probability of development of a site (cell) with high regional conductance and irreplaceability. The regional vulnerability index measures the vulnerability of an irreplaceable cell with high regional conductance to the loss of its connectivity value caused by future development; it is a function of regional conductance, regional irreplaceability and the integrated future probability of development, and is one of the major spatial components in our **landscape conservation design** framework

Representative species, **surrogate species**. A species whose habitat needs, ecosystem function, or management responses are similar to a group of other species (USFWS). Importantly, representative (or surrogate) species can be selected as focal species for conservation because of their role in representing many other species with similar requirements.

Resiliency. The capacity to recover from **disturbance** and **stress**; more specifically, it refers to the amount of disturbance and stress a system can absorb and still remain within the same state or domain of attraction (e.g., resistance to permanent change in the composition, structure and function of the system) (Holling 1973, 1996). Resiliency is a function of the amount and accessibility of similar **ecological settings** in the neighborhood of a focal cell. Note, resiliency is both a function of the ecological setting, since some settings are naturally more resilient to disturbance and stress (e.g., a small isolated wetland is less resilient to species loss than an extensive and well-connected wetland because the latter has better opportunities for recolonization of constituent species), and the level of anthropogenic stress, since the greater the stressor the less likely the system will be able to fully recover. Resiliency is an intrinsic attribute of a site that contributes to the **ecological integrity** of the site itself and thus, by extension, confers ecological integrity to the landscape as a whole. Resiliency is measured using a weighted linear combination of two core **metrics**: connectedness and similarity, although there is a separate version of connectedness for terrestrial and aquatic systems

Resistance, **landscape resistance**, **resistant landscape**, **resistance surface**, **cost**, **cost surface**. The **ecological distance** between a focal cell and other cells in the landscape. Resistance represents the willingness of an organism to cross a particular environment, the physiological cost of moving through a particular environment, the reduction in survival for the organism moving through a particular environment, or an integration of all these factors (Zeller et al. 2012). Resistance estimation is most commonly accomplished by parameterizing environmental variables across a 'resistance' or 'cost' to movement continuum, where a low resistance denotes ease of movement and a high resistance denotes restricted movement, or is used to represent an absolute barrier to movement. 'Friction' and 'impedance' to movement or their inverse, 'permeability' and 'conductivity' to movement, are also terms used to describe these travel surfaces (Singleton et al. 2002; Chardon et al. 2003; Sutcliffe et al. 2003).

Resistant kernel. A modification of the classic kernel estimator applied to a **resistant landscape** (where resistance is based on **ecological distance**); refers either to a kernel applied to a single point, or the sum of kernels applied to multiple points in a landscape.

Site. A local area defined either as an individual grid cell or potentially a spatial unit (e.g. parcel) comprised of multiple contiguous cells. A site (typically a cell) is the finest unit of observation and the spatial grain of the analysis.

Stressor. An event or action that modifies the **ecological condition** and/or **ecological integrity** of an ecosystem. Note, here we are principally interested in anthropogenic stressors; i.e., those caused by human actions.

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