**ELECTRONIC SUPPLEMENTARY MATERIAL**

**Integrating the aesthetic value of landscapes and biological diversity**

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**Supplementary Table 1** Example of metrics used in landscape aesthetic assessment. Assessment metrics inspired by landscape ecological studies are based either on statistical analyses or on perceptions. Metrics based on statistical analyses of images describe landscape composition, landscape configuration, ecological value, visual scales or colorimetry. They are generally computed using GIS modelling. Metrics based on perception describe cultural, cognitive and psychological aspects of aesthetic experience. They aim to explain aesthetic preferences ‘in the eyes of the observer’ and are generally assessed by photographic surveys submitted to people or experts judgement. Presence/absence of particular elements in the landscape are also used to assess landscape aesthetic, e.g. presence of water or man-made elements.

|  |  |  |
| --- | --- | --- |
| **Metric** | **Example** | **References** |
| **Spatial composition** |  |  |
| Landscape diversity | High value = many different elements | De La Fuente de Val et al 2006 Dramstad et al 2006 |
| Landscape complexity | Diversity, richness of landscape elements and features, interspersion of pattern | Fry et al 2009 |
| Structural diversity | Components providing aesthetic ecosystem services | De Groot et al 2010 |
| Heterogeneity | Heterogeneity index (heterogeneity of landscape composition) Degree of heterogeneity | Dramstad et al 2006 from Fjellstad et al 2001 Dupont et al 2014 |
| Number of features | State indicator of aesthetic services (how much of the service is present) | De Groot et al 2010 |
| Area of features | State indicator of aesthetic services (how much of the service is present) | De Groot et al 2010 |
| Complexity | Indicate whether the spatial structure is simple or complex | De La Fuente de Val et al 2006 |
| Visual variety | Variety of visual elements | Roth & Gruehn 2012 |
| Fitness | Order divided by complexity, based on Shannon's entropy | Walsh & Grade 2011 |
| Number of land types | Number of different land types | Dramstad et al 2006 |
| Land type diversity | Shannon's diversity index | Herbst et al 2009 |
| Land type percent area | Percent of total area of each land type | Palmer 2004 |
| Pattern | Assign a high value to landscapes presenting regularly repeated elements or clear patterns | De La Fuente de Val et al 2006 |
| **Spatial configuration** |  |  |
| **Patches** |  |  |
| Number of patches | Number of patches in a landscape mosaic | De La Fuente de Val et al 2006 Dramstad et al 2006 Ode et al 2009 |
| Patch-shape | Assign a high value to a landscape presenting elements with irregular shapes Size of the patches | De La Fuente de Val et al 2006 Ode et al 2009 |
| Patch diversity | Diversity of patches | De La Fuente de Val et al 2006 Frank et al 2013 |
| Patch richness | Number of different types of patches, independent of the number of patches of each type | De La Fuente de Val et al 2006 |
| Patch density | Number of patches per 100 ha | Palmer 2004 |
| Patch richness density | Number of different land uses per 100 ha | Palmer 2004 |
| Fractal dimension of patches | Mean fractal dimension for all patches, quantifies the complexity of patch-shapes | De La Fuente de Val et al 2006 |
| Largest patch index | Percent of total area occupied by the largest patch | Palmer 2004 |
| **Edges** |  |  |
| Edge density | Density of edges between different classes Meters of edge, including the background edge, per hectare | Herbst et al 2009 Palmer 2004 |
| Shape Index | Total edge in meters, divided by the root of the total area in meters squared,  and adjusted for a standard square raster | Palmer 2004 Frank et al 2013 |
| Shape Index of edges | Complex shapes; Intermediate complex shapes; Geometric shapes | Ode et al 2009 |
| **Evenness** |  |  |
| Shannon's index | Shannon's evenness index | Palmer 2004 |
| Simpson's index | Simpson’s evenness index | De La Fuente de Val et al 2006 |
| **Contagion** | To what extent landscape elements are aggregated | De La Fuente de Val et al 2006 |
| **Interspersion** | How landscape elements are interspersed | De La Fuente de Val et al 2006 |
| **Scale - visibility** |  |  |
| Openness | Percent of open area Degree of openess Percentage of open land in the view | Dramstad et al 2006 Dupont et al 2014 Tveit 2009 |
| Scale | No element presents scale effect; presence of scale effect | Arriaza et al 2004 Cenzig 2014 |
| Visibility | Visibility of the landscape | De La Fuente de Val et al 2006 |
| Visual scale | Landscape rooms or perceptual units: their size, shape and diversity, degree of openness Visual scale categories: from 'small' to 'large' landscape rooms | Fry et al 2009 Tveit 2009 |
| Relief | Topographic heterogeneity Presence, type | De La Fuente de Val et al 2006 Garcia-Llorente et al 2012 |
| Horizon | Almost flat, slightly wavy, some mountains, mountains dominate the landscape | Arriaza et al 2004 Cenzig 2014 |
| Perspective | Assign a high value when the place in the landscape has a wide or panoramic perspective | De La Fuente de Val et al 2006 |
| Vast | To what extent landscape is considered vast (immense) | Sevenant & Antrop 2009 |
| **Ecology** |  |  |
| Biodiversity | Species richness, evenness, and Shannon's diversity index | Hale et al 2005 |
| Vegetation percent cover | Percentage of landscape covered by vegetation | Arriaza et al 2004 Cenzig 2014 |
| Level of succession | Border width of succession species in the landscape | Ode et al 2009 |
| Afforestation pattern | Afforestation from forest edge, continuous afforestation,  mosaic afforestation, linear afforestation | Ruskule et al 2013 |
| Wilderness | How a landscape is a ‘rugged untouched landscape’, ‘devoid of human beings’,  with ‘no contact with the outside world’ Quantity of man-made elements | Beza 2010 Arriaza et al 2004 Cenzig 2014 |
| Greenness | Function providing aesthetic ecosystem services | De Groot et al 2010 |
| Naturalness | Perceived naturalness Gradual indication of the degree of disturbance by man  Closeness to a perceived natural state | Dobbie 2013 Frank et al 2013 Fry et al 2009 Ode et al 2009 Ruskule et al 2013 |
| **Colorimetry** |  |  |
| Color contrast | Weak colour contrast; clear colour contrast | Arriaza et al 2004 Cenzig 2014 |
| Number of colours | One, two, three or more Assign a high value if the landscape have many different colors | Arriaza et al 2004 Cenzig 2014 De La Fuente de Val et al 2006 |
| Colour | Diversity, Contrast | Arriaza et al 2004 |
| Texture | Diversity, Contrast | Arriaza et al 2004 Cenzig 2014 |
| **Function** |  |  |
| Attractive vegetation | To what extent the vegetation is considered attractive | Sevenant & Antrop 2009 |
| Valuable for conservation | To what extent the landscape is considered valuable for conservation | Sevenant & Antrop 2009 |
| Bearing a lot of functions | To what extent the landscape is considered bearing a lot of functions | Sevenant & Antrop 2009 |
| **Aesthetic (scenic quality)** |  |  |
| Scenic beauty | Assigns a value to the landscape according to its scenic beauty Ageableness | De La Fuente de Val et al 2006 |
| Beauty | Perceived beauty (aesthetic) | Roth & Gruehn 2012 |
| Variety | Perceived variety (diversity) | Roth & Gruehn 2012 |
| Peculiarity | Perceived peculiarity (oddity) | Roth & Gruehn 2012 |
| Overall scenic quality | Perceived overall scenic quality (aesthetic) | Roth & Gruehn 2012 |
| **Feelings and Emotions** |  |  |
| Harmony | None, presence of harmony (peacefulness) | Arriaza et al 2004 Cenzig 2014 |
| Tranquility | Function providing aesthetic ecosystem services (serenity) | De Groot et al 2010 |
| Familiar | To what extent the landscape is considered as familiar (recognizable) | Sevenant & Antrop 2009 |
| Quiet and silent | To what extent the landscape is considered as quiet and silentious | Sevenant & Antrop 2009 |
| Accessible | To what extent the landscape is considered as accessible (reachable) | Sevenant & Antrop 2009 |
| Typical | To what extent the landscape is considered as typical (emblematic) | Sevenant & Antrop 2009 |
| Uniquiness/distinctiveness | Perceived uniqueness and distinctiveness (singularity) | Roth & Gruehn 2012 |
| Excitement | Feeling of excitement (exaltation) | Beza 2010 |
| Risk | Assign a high score if you perceive the components  of the image to evoke hazards or dangers | De La Fuente de Val et al 2006 |
| Desolation | Feeling of desolation (desperation) | Ruskule et al 2013 |
| Apathy | Feeling of apathy (indifference) | Ruskule et al 2013 |
| Depression | Feeling of depression (dispiritedness) | Ruskule et al 2013 |
| Shame | Feeling of shame (dishonor) | Ruskule et al 2013 |
| Enjoying revival of nature | Feeling of enjoying revival of nature (relief) | Ruskule et al 2013 |
| Loneliness | Feeling of loneliness (seclusion) | Ruskule et al 2013 |
| Fear | Feeling of fear (scare) | Ruskule et al 2013 |
| **Concepts from Kaplan's model** |  |  |
| Complexity | Indicates whether the spatial structure is simple or complex Diversity, richness of landscape elements and features, interspersion of pattern To what extent the landscape is considered varied or homogenous | De La Fuente de Val et al 2006 Dobbie 2013 Sevenant & Antrop 2009 |
| Coherence – Orderliness  Unity – Homogeneity | Indicates to what degree the picture is coherent, ordered, united, homogeneous To what extent the landscape is considered as coherent, ordered, united, homogeneous | Cañas et al 2009 De La Fuente de Val et al 2006 Dobbie 2013 Sevenant & Antrop 2009 |
| Legibility | Assigns a low value if you consider that the landcsape is confused or difficult to interpret | De La Fuente de Val et al 2006 |
| Mystery – Inviting to visit | Assigns a high value if you perceive the landscape is hiding information,  that there are elements hidden to the observer To what extent the ladnscape is considered inviting to visit for recreation | De La Fuente de Val et al 2006  Sevenant & Antrop 2009 |
| **Human and Cultural aspects** |  |  |
| Human influenced | To what extent the landscape is considered human-influenced (anthropized) | Sevenant & Antrop 2009 |
| Well-maintened | To what extent the landscape is considered well-maintened (well-managed) | Sevenant & Antrop 2009 |
| Unspoiled | To what extent the landscape is considered unspoiled (preserved) | Sevenant & Antrop 2009 |
| Historical importance – Historicity | Historical continuity and historical richness, different time layers, amount and diversity of cultural elements To what extent the landscape is considered as historically important (historical patrimony) | Fry et al 2009 Sevenant & Antrop 2009 |
| Ephemera | Changes with season, weather or other temporal effects | Fry et al 2009 |
| Cultural resources | Type, presence, interest, visibility | Cañas et al 2009 |
| Folk culture | Type, presence | Di et al 2010 |
| Stewardship | Sense of order and care, perceived accordance to an ‘‘ideal’’ situation reflecting human care  through active and careful management | Fry et al 2009 |
| Disturbance | Lack of contextual fit and coherence, constructions and interventions | Fry et al 2009 |
| Expression | Psychological attribute. Measured by 'Stimulation' and 'Symbolism' | Cañas et al 2009 |
| Imageability | Qualities of a landscape to create a strong visual image in the observer,  and making distinguishable and memorable | Fry et al 2009 |
| Hemeroby | Intensity of human impact on ecosystems | Frank et al 2013 |
| **Antropic elements** |  |  |
| Man-made elements | Presence of man-made elements (positive: sights and typical houses;  or negative: roads, industries, power-line, etc.) | Arriaza et al 2004 Cenzig 2014 |
| Traditional human activities | Type, presence | Garcia-Llorente et al 2012 |
| Land use | Type, presence | Cañas et al 2009 |
| Housing density | Sum of the housing units divided by the sum of census blocks per site | Hale et al 2005 |
| Alterations | Intrusion, fragmentation, horizontal line, obstruction of view | Cañas et al 2009 |
| **Natural elements** |  |  |
| **Non-Living** |  |  |
| Water body | Type, presence | Di et al 2010 Dramstad et al 2006 |
| Water flow | No movement, movement Snow summit, riparian vegetation, dam | Arriaza et al 2004 Garcia-Llorente et al 2012 |
| Water movement | No movement, movement | Cenzig, 2014 |
| Water | Type, shorelines, movement, quantity | Cañas et al 2009 |
| Waterscapes | No water, river, lake, dam | Arriaza et al 2004 |
| Amount of water | No water, river, lake, sea | Cenzig, 2014 |
| Moutains | Type, presence | Di et al 2010 |
| Form of the terrain | Type | Cañas et al 2009 |
| Snow | Cover Snow summit | Cañas et al 2009 Garcia-Llorente et al 2012 |
| Views | Type, presence | Cañas et al 2009 |
| Sounds | Type, presence | Cañas et al 2009 |
| Smells | Type, presence | Cañas et al 2009 |
| Atmospheric phenomena | Presence, type | Di et al 2010 |
| **Living** |  |  |
| Vegetation | Cover, density, quality, type, structure, complexity | Cañas et al 2009 Di et al 2010 |
| Type of vegetation | No vegetation; herbaceous and bushes; mix vegetation (bushes + trees); trees | Cenzig 2014 |
| Fauna | Presence, interest, Visibility, Amplitude | Cañas et al 2009 |
| Animal | Presence of familiar animals, animal species, national-level protected species | Di et al 2010 |

**Supplementary Table 2** Example of metrics used in landscape biodiversity assessment. Taxonomic diversity **(a)** is based on the number and abundance of species in a site or within a community, used to estimate species diversity. Taxonomic diversity indices are based on the probabilistic concept of entropy, which represents the quantitative uncertainty of an information. Based on the same principle, phylogenetic diversity **(b)** and functional diversity **(c)** use more sophisticated metrics based respectively on the phylogenetic distances or on the functional traits as basic units.

**a) Taxonomic diversity**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Index** | **Abbr.** | **Formula** | **Description** | **Based on** |
| Richness | S |  | Total number of species in the community. A community is an  association of interacting species inhabiting some-defined area | Number of species |
| Abundance | N | Number of individuals or species found per sample *i* = individuals *I* = total sample | Number of individuals |
| Relative abundance | *pi* | N*i*/ N | Number of species (or individuals) from one group divided by the total number of species (or total number of individuals) from all groups. Refers to how common or rare a species is relative to other species in a given location or community | Species richness |
| Diversity |  |  |  |  |
| Simpson index | D | Measures the probability that two individuals randomly selected from a sample will belong to the same species. It is a dominance index because it gives more weight to common or dominant species | Species richness and  relative abundance |
| Shannon index | H |  | Characterize species diversity in a community. It is an information statistic index, which means it assumes all species are represented in a sample and that they are randomly sampled | Species richness  and relative abundance |
| Evenness | EH |  | Evenness is a measure of the relative abundance of different  species making up the richness of an area; i.e. measure of how close in numbers each species in an environment are | Shannon idex and  species richness |
| Quadratic diversity | Q | Measures the average taxonomic distance between species | *pi*= proportion of individuals in species *i* *dij* = taxonomic distance between species *i* and *j* |

**b) Phylogenetic diversity**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Background** | **Abbr.** | **Description** | **References** | |  | | --- | |  | |  |
| Tree |  | A rooted phylogenetic tree summarizes hypothesized  evolutionary relationships among species or other biological units such as lineages within species | Vellend et al 2011 | A  B  C  Branch  Root  Node  Evolutionary time  Leave |  |
| Tips (or 'leaves') |  | Represents species of the tree | Vellend et al 2011 |  |  |
| Node | *n* | Represents the most recent common ancestor of species descending from that point | Vellend et al 2011 |  |  |
| Phylogenetic distance | *dij* | Phylogenetic distance between species *i* and *j* | Waewick & Clarke 1995 |  |  |
| Branch lenghts | *l(b)* | Represents the accumulation of evolutionary change  or the passage of time | Vellend et al 2011; Allen et al 2009 |  |  |
| Proportion | *p(b)* | Proportion of individuals in the community who  are represented by tips | Allen et al 2009 |  |  |
| **Index** | **Abbr.** | **Description** | **Formula** | **Based on** | **References** |
| Phylogenetic diversity | PD | Sum of all branch lengths in the portion of a phylogenetic tree |  | Branch lenghts *l(b)* | Faith 1992 |
| Mean Phylogenetic Distance | MPD | Mean phylogenetic distance between each pair of species |  | *dij* = phylogenetic distance between species *ai* = abundance of species *i* | Webb 2000;  Warwick & Clarke 1995 |
| Sum of Phylogenetic Distance | SPD | Sum of phylogenetic distances between each pair  of species (= MPD multiplied by the number of species pairs) |  | *dij*= phylogenetic distance between species *S* = number of species | Crozier 1997;  Helmus et al 2007 |
| Mean nearest neighbour distance | MNND | Mean phylogenetic distance from each species to its closest  relative in the focal species set |  | *dij*= phylogenetic distance between species *aj* = abundance of species *j* | Webb 2000 |
| Quadratic phylogenetic diversity | Q | Measures the average taxonomic distance between species |  | *pi*= proportion of individuals in species *dij* = phylogenetic distance between species | Rao 1982 |
| Unamed | H*d* | Encompass species richness and Shannon index |  | *pi*= proportion of individuals in species *dij* = phylogenetic distance between species | Ricotta & Szeidl 2006 |
| Phylogenetic entropy | H*p* | Places a high value on distinctive species but has the  property that when members of a species become rare in proportion to other species, it is never desirable to eliminate them |  | Branch lenghts *l(b)* Proportion *p(b)* | Allen et al 2009 |

**c) Functional diversity**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Background** |  | **Description** | **References** |  |  |
| Functional trait |  | Defines species in terms of their ecological roles -  how they interact with the environment and with other species | Diaz and Cabido, 2001 |  |  |
| Distance matrix |  | Provides information on the functional distance between all pairs of species within the community |  |  |  |
| Hierarchical classification |  | Classes species into groups as function of functional  distances |  |  |  |
| **Index** | **Abbr.** | **Description** | **Formula** | **Based on** | **References** |
| Functional Attribute Diversity | FAD | Sum of pairwise distances between species |  | Distance matrix *dij*= dissimilarity between species *i* and *j* *S* = species richness | Walker et al 1999 |
| Modified Functional Attribute Diversity | MFAD | Sum of pairwise distances between functional units |  | Distance matrix *N*= total number of functional traits *dij*= dissimilarity between species | Schmera et al 2009 |
| Functional Diversity | FD | Sum of branch length of a functional classification |  | Hierarchical classification *i'* = branch presence/absence rox vector *h2* = branch lenght vector | Petchey & Gaston 2002 |
| Generalized Functional diversity | GFD | Sum of branch length of a functional classification |  | Hierarchical classification *i'* = branch presence/absence rox vector *h2* = branch lenght vector | Mouchet et al 2008 |
| Rao's quadratic entropy | Q | Sum of pairwise distances between species weighted by relative abundance |  | Distance matrix *dij*= dissimilarity between species  *pi* = relative abundances of species *S* = species richness | Rao 1982 |
| Functional Richness | FRic | Convex Hull Volume | Quickhull algorithm | Trait values | Cornwell et al 2006; Villéger et al 2008 |
| Functional Divergence | FDiv | Species deviance from the mean distance to the centre of gravity weighted by relative abundance |  | Trait values ∆*d*= sum of abundance-weighted deviances ∆ǀ*d*ǀ = absolute abundance-weighted deviances from the centre of gravity *dG* = mean distance to the centre of gravity | Villéger et al 2008 |
| Functional Evenness | FEve | Sum of MST branch length weighted by  relative abundance |  | Trait values *S* = species richness *PEW* = partial weighted evenness | Villéger et al 2008 |

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**(Palmer 2004)**

**(Ode et al. 2009)**

**(Frank et al. 2013)**

**(Dupont et al. 2014)**

**(Tveit 2009)**

**(Arriaza et al. 2004)**

**(Cenzig 2014)**

**(Garcia-Llorente et al. 2012)**

**(Sevenant & Antrop 2009)**

**(Hale et al. 2005)**

**(Ruskule et al. 2013)**

**(Beza 2010)**

**(Dobbie 2013)**

**(Roth 2012)**

**(Cañas et al. 2009)**

**(Di et al. 2010)**

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**(Warwick & Clarke 1995)**

**(Allen et al. 2009)**

**(Faith 1992)**

**(Webb 2000)**

**(Rao 1982)**

**(Ricotta & Szeidl 2006)**

**(Crozier 1997)**

**(Helmus et al. 2007)**

**(Díaz 2001)**

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