

Table S1. Sentinel Spectral Indices for Ecological Analysis

Index Name	Abbreviation	Formula	Ecological Meaning	Reference
Aerosol Contrast Index	AC_Index	$(B2 - B1) / (B1 + B2)$	This spectral index is applied for detailed examination of coastal and inland waters. It is capable of observing sediments, particles, organic matter and chlorophyll-rich phytoplankton in these waters.	[1]
Blue-Green Index	BIG2	$B2 / B3$	BIG2 distinguishes between vegetation and water or soil; sensitive to pigment concentration.	[2]
Green Leaf Index	GLI	$(2 * B3 - B4 - B2) / (2 * B3 + B4 + B2)$	Indicates vegetation density and photosynthetic activity. The index ranges from -1 to +1. A negative value indicates soil or dead cover, while a positive value indicates green leaves and stems. A threshold with a value close to 0 divides the image into two classes: green leaves and soil or non-living cover.	[3]
Green NDVI	GNDVI	$(B7 - B3) / (B7 + B3)$	Highly sensitive to chlorophyll content; used in vegetation stress monitoring.	[4]
Land Surface Water Index	LSWI	$(B5 - B6) / (B5 + B6)$	Reflects water content in vegetation and soil; used for drought monitoring.	[5]
Modified NDWI	MNDW	$(B3 - B11) / (B3 + B11)$	Enhanced water body extraction by replacing NIR with SWIR.	[6]
Normalized Burn Ratio Index	NBRI	$(B8 - B12) / (B8 + B12)$	Detects burned areas and vegetation loss due to fires.	[7]
Normalized Difference Bareness Index	NDBaI	$(B6 - B11) / (B6 + B11)$	Extracts bare soil areas automatically.	[8]
Normalized Difference Chlorophyll-a	NDChla	$(B3 - B4) / (B3 + B4)$	Estimates chlorophyll-a concentration in water.	[9]
Normalized Difference Green Chlorophyll Index	NDGCI	$(B8a - B3) / (B8a + B3)$	Estimates leaf chlorophyll content, indicator of plant health.	[10]
Normalized Difference Index	NDI	$(B12 - B7) / (B12 + B7)$	Used to estimate soil salinity.	[11]
Normalized Difference Infrared Index	NDII	$(B8 - B11) / (B8 + B11)$	Indicates water content in vegetation; used for drought assessment.	[12]
Normalized Difference Iron Oxide	NDIO	$(B4 - B2) / (B2 + B4)$	Detection of ferric iron oxides.	[13]
Blue-normalized difference vegetation index	BNDVI	$(B12 - B1) / (B12 + B1)$	The BNDVI is a modification of the standard NDVI, where a blue channel is used instead of the red channel (Red). Its sensitivity is more focused on low chlorophyll levels, which allows it to better detect stressed or degraded plants. The use of the blue channel makes the index more stable in cases of noise pollution or shadows, which is especially important in the early stages of plant growth.	[14]
Normalized Difference Red Edge Index	NDRE	$(B7 - B5) / (B7 + B5)$	NDRE is a modified version of NDVI that uses red-edge instead of red band. Red-edge is a spectral region between red and NIR (~700-740 nm) that is sensitive to chlorophyll content, even in dense vegetation. The index does not saturate at high biomass, unlike NDVI. It is a better indicator of chlorophyll, especially in the later stages of crop growth, when NDVI is no longer sensitive. Sensitive to nitrogen stress - as chlorophyll content is often directly related to nitrogen content in plants. It is used to assess stress associated with water and nitrogen deficiencies. Reliable for partial soil coverage - less dependent on cover density than other	[15]

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			indices. It has a high correlation with the nitrogen content in the leaves, surpassing other vegetation indices in this regard.	
Normalized Difference Red-Edge Improved	NDREI	$\frac{(B8 - B5)}{(B8 + B5)}$	NDREI is an improved version of the NDRE index, which uses RE1 (B6 or B7) instead of RE2 (B5), as well as near-infrared (NIR). The choice of RE1 + NIR provides better spectral sensitivity to early changes in chlorophyll and plant condition. The index reduces saturation, which is typical for NDVI, and responds better to light plant stress, even with a high leaf area index (LAI). The index is highly sensitive to chlorophyll concentration. NDREI accurately reflects chlorophyll even in dense cover. It is optimal for assessing nitrogen supply. It is particularly effective in crops where nitrogen is closely related to chlorophyll content. Less dependent on cover density than NDVI or GNDVI. Increased stability when changing the sun angle or atmospheric conditions due to the use of a red-edge channel closer to the NIR. Effective for monitoring late vegetation stages when NDVI becomes less sensitive.	[15]
Normalized Difference Tillage Index	NDTI	$\frac{(B11 - B12)}{(B11 + B12)}$	The index uses two SWIR channels that are sensitive to soil moisture content and surface structure. The NDTI index detects the difference between treated and untreated soil based on their different reflectivity in the SWIR range. Changes in the surface structure (e.g. after ploughing or harrowing) affect the spectral response that this index captures. High ability to distinguish between tillage methods, e.g. no-till, minimum-till, conventional tillage. It is resistant to changes in vegetation cover and is particularly effective in areas with no or minimal vegetation. It can be used to assess erosion vulnerability, as the surface structure directly affects erosion processes.	[16]
Normalized Difference Total Suspended Matter Index	NDTSM	$\frac{(B7 - B2)}{(B7 + B2)}$	Estimates total suspended matter in water bodies.	[17]
Normalized Difference Vegetation Index	NDVI	$\frac{(B8 - B4)}{(B8 + B4)}$	Indicates vegetation productivity and greenness. One of the most popular vegetation indices.	[18]
Normalized Difference Water Index 1	NDWI1	$\frac{(B3 - B8)}{(B3 + B8)}$	NDWI1 exploits the difference in spectral reflectivity between water and land in the green and NIR bands. Positive values (close to +1): indicate open water. Zero or negative values are typical for vegetation and soils. The main application is to identify lakes, rivers, and reservoirs in images. NDWI1 can be an indicator of overall turbidity.	[19]
Normalized Difference Water Index 2	NDWI2	$\frac{(B5 - B12)}{(B5 + B12)}$	NDWI ₂ is sensitive to the moisture content of soil and vegetation. It is primarily applied to assess water stress in plants and soil moisture levels. Low NDWI ₂ values indicate drought or reduced moisture. The NDWI ₂ is not intended to detect water as much as the classic NDWI1, but to indicate the moisture in the environment. NDWI ₂ is often used under the name NDMI (Normalised Difference Moisture Index).	[20]
Red-Blue NDVI	RBNDVI	$\frac{(B8 - (B5 + B1))}{(B8 + B5 + B1)}$	A three-component index derived from NDVI can better assess mixed vegetation and soil conditions. The B1 (coastal aerosol) channel is sensitive to aerosols and dust, so its inclusion in the denominator allows for normalisation of the effect of atmospheric influence on reflectance. The B5 red-edge channel provides a better assessment of vegetation stress conditions, including early signs of wilting, dryness, or salinity. The integration of information on soil, vegetation and atmosphere makes the index more stable in arid and semi-arid regions, where other indices	[11]

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			have a lower correlation with real indicators of land cover. It is used for monitoring soil salinity, assessing vegetation cover in saline environments, and has improved discriminatory ability to distinguish between vegetation, bare soil and saline areas.	
Red Edge NDVI 1	RedEdge_NDVI1	$\frac{(B6 - B4)}{(B6 + B4)}$	This index is a variant of NDVI, where instead of NIR, red-edge, which is sensitive to chlorophyll, is used, and instead of the traditional green, red, which is highly absorbed by pigments, is used. The red-edge range (680-750 nm) is characterised by a sharp transition between chlorophyll absorption and mesophyll reflection. B6 is particularly sensitive to early changes in chlorophyll, making it useful for detecting subtle or initial changes in vegetation. Red-edge reflectance is predominantly driven by chlorophyll content, not just leaf area, which allows for an assessment of the physiological state of plants. Red Edge NDVI 1 displays LAI changes much more accurately than classic NDVI. It allows you to identify the stages of plant development, initial signs of stress, leaf aging or nutrient deficiencies.	[21]
Red Edge NDVI 2	RedEdge_NDVI2	$\frac{(B7 - B4)}{(B7 + B4)}$	This index is a modified NDVI based solely on the red-edge spectrum. It can be considered a highly specialised index for assessing the physiological state of plants, in particular chlorophyll content. The index is particularly sensitive to chlorophyll concentration in leaves and less sensitive to soil background. Even small changes in the structure or concentration of pigments can significantly affect the index value. Red-edge NDVI 2 does not reach a plateau as quickly at high LAI values, which allows for better distinction of dense crowns. Relatively less dependent on water content: this index focuses more specifically on photosynthetic pigments.	[21]
Red Edge Difference Index	REDI	$\frac{(B7 - B6)}{(B7 + B6)}$	The index is highly sensitive to changes in chlorophyll. The index compares two adjacent red-edge bands, where subtle changes in the slope of the spectral curve are recorded as chlorophyll content increases or decreases. The index also has low sensitivity to soil and water background. A narrow spectral range between channels B6 and B7 minimises the influence of background components, particularly in the case of incomplete vegetation coverage. In dense vegetation, this index is less prone to saturation than classical vegetation indices. It can be used for high-precision analyses of the dynamics of changes in vegetation condition due to its spectral stability. The index is sensitive to changes in chlorophyll content, so it is efficient for detecting nutritional stress, aging, and pest damage.	[22]
Red Edge Normalized Difference Vegetation Index	RENDVI	$\frac{(B7 - B5)}{(B7 + B5)}$	Unlike the classical NDVI, which is based on the red and NIR bands, RENDVI uses two red-edge channels, which gives high sensitivity to chlorophyll concentration without saturation under high LAI conditions. The index is particularly effective in detecting plant stress, nitrogen deficiency, and aging. Since the reflections in the red-edge are formed mainly by leaves, the index is less sensitive to the brightness of the litter layer than the classical indices. It shows changes in chlorophyll content even under early stress, before visual symptoms appear. Suitable for analysing the dynamics of medium and dense vegetation in time series.	[4]
Rock Index	RI	$\frac{(B3 - B12)}{(B3 + B12)}$	Index based on the contrast of visible and SWIR reflectance. The green band (B3) is well reflected by most illuminated surfaces	[23]

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			(including rocks), while the SWIR band (B12) is sensitive to moisture, clay minerals, carbonates and sulphates. Rocks with high reflectivity in the visible spectrum but low SWIR reflectivity (quartzite, flint) give high positive values. Mixed moistened clay and altered rocks (with hydrothermal influence) exhibit lower or negative values. The index is analogous to NDVI for geological purposes. However, RI characterises rock surface types instead of vegetation. It is used to identify rock outcrops, especially in open, dry regions. High RI values (closer to +1) indicate dry, reflective surfaces (light rocks, quartzites). Low RI values (closer to -1) may indicate wet, hydrothermally altered areas or dense vegetation.	
Structure Insensitive Pigment Index	SIPI	$\frac{(B8 - B2)}{(B8 - B4)}$	SIPI is developed to minimise the influence of structural characteristics of the plant cover (e.g. leaf area, leaf distribution) on the assessment of plant pigment composition. SIPI increases with decreasing relative chlorophyll content and increasing carotenoids, and is therefore a marker of stress, aging, and leaf yellowing. SIPI $\approx$ 1.0 indicates a high chlorophyll content and low stress level. SIPI > 1.2 indicates an increase in the proportion of carotenoids, possible degradation or stress. SIPI effectively reflects changes in the pigment balance due to water deficiency, pathogens, and nutrient deficiencies. It is used to monitor the degradation of stands in forests and parks.	[24]
Sentinel-2 Vegetation Salinity Index	SVSI	$\frac{(B4 - B2)}{(B5 + B11)}$	The index assesses the difference between the visual absorption of pigments (chlorophyll, carotenoids) in the blue/red range (B2, B4) and the combined contribution of leaf structure and water (B5 + B11). The index reveals the secondary effects of soil salinity primarily through a decrease in chlorophyll, a decrease in water content, and damage to leaf structure. Indicates the accumulation of Cl ⁻ and Na ⁺ ions in plant leaves through their spectral effect on pigment composition and moisture content. It allows to assess the level of plant stress in saline areas.	[25]
Tasseled cap greenness	(TCI GREEN)	$TCI\ GREEN = -0.2848 \cdot B02 - 0.2435 \cdot B03 - 0.5436 \cdot B04 + 0.7243 \cdot B08 + 0.0840 \cdot B11 - 0.1800 \cdot B12$	The TCI transforms spectral data into three composite indices—brightness, greenness, and wetness—capturing soil reflectance, vegetation vigor, and surface moisture, respectively	[26]
Tasseled cap brightness	(TCI BRIGHT)	$TCI\ BRIGHT = 0.3037 \cdot B02 + 0.2793 \cdot B03 + 0.4743 \cdot B04 + 0.5585 \cdot B08 + 0.5082 \cdot B11 + 0.1863 \cdot B12$	The TCI transforms spectral data into three composite indices—brightness, greenness, and wetness—capturing soil reflectance, vegetation vigor, and surface moisture, respectively	[26]
Tasseled cap wetness	(TCI WET)	$TCI\ WET = 0.1509 \cdot B02 + 0.1973 \cdot B03 + 0.3279 \cdot B04 + 0.3406 \cdot B08 - 0.7112 \cdot B11 - 0.4572 \cdot B12$	The TCI transforms spectral data into three composite indices—brightness, greenness, and wetness—capturing soil reflectance, vegetation vigor, and surface moisture, respectively	[26]
Modified soil-adjusted vegetation index	(MSAVI)	$MSAVI = \frac{2B08 + 1 - \sqrt{(2B08 + 1)^2 - 8(B08 - B04)}}{2}$	MSAVI is used because, in sparsely vegetated areas, the reflectance measured by the sensor is strongly influenced by exposed soil, so “greenness” indices can vary simply due to soil brightness rather than real changes in plant cover or condition. By reducing the soil-background effect, MSAVI gives a cleaner vegetation signal: values are more comparable across sites with different soil brightness, and changes over time more likely reflect actual vegetation dynamics (cover, vigor, stress) instead of fluctuations in bare soil contribution.	[27,28]
Chlorophyll green	(CIGRN)	$CIGRN = \frac{B08}{B03} - 1$	The CIGRN is a vegetation index that leverages reflectance in the green band to estimate chlorophyll content in plants, indicating plant health, photosynthetic activity, and nitrogen content.	[29]

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Visual atmospheric resistance index	(VARI)	$VARI = \frac{B03 - B04}{B03 + B04 - B02}$	The VARI enhances vegetation detection in the visible spectrum by reducing the impact of atmospheric interference and variable illumination.	[30]
Modified triangular vegetation index	(MTVI2)	$MTVI2 = \frac{1.5 * (1.2 * (B08 - B03) - 2.5 * (B04 - B03))}{\sqrt{(2 * B08 + 1)^2 - (6 * B08 - 5 * \sqrt{B04})} - 0.5}$	The MTVI2 estimates chlorophyll content in plant canopies, with minimal sensitivity to variations in leaf area index.	[31]

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